G.E.C. Journal

VOL. I. NOVEMBER, 1930 No. 3.

CONTENTS

	PAGE
FRONTISPIECE: THE E.M.V. "CEMENTKARRIER"	90
DIESEL-ELECTRIC PROPULSION OF THE E.M.V. "CEMENTKARRIER" *By C. Wallace Saunders and S. A. G. Emms.*	91
THE MANUFACTURE AND TESTING OF ACCESSORIES FOR OIL-FILLED CABLES *By R. E. Horley.*	102
INDUSTRIAL ELECTRIC HEATING—PART I *By Verdon O. Cutts.*	111
THE TESTING OF DRY CELLS *By R. W. W. Sanderson.*	115
THE ELECTRIFICATION OF A WAX BATTIK PRINTING FACTORY *By F. Barlow and D. C. Rogerson.*	123
THE DESIGN OF HIGH POWER HEAVY OIL ENGINES *By G. A. Mellor.*	127

Published by

THE GENERAL ELECTRIC Co., LTD.

Magnet House Kingsway London.

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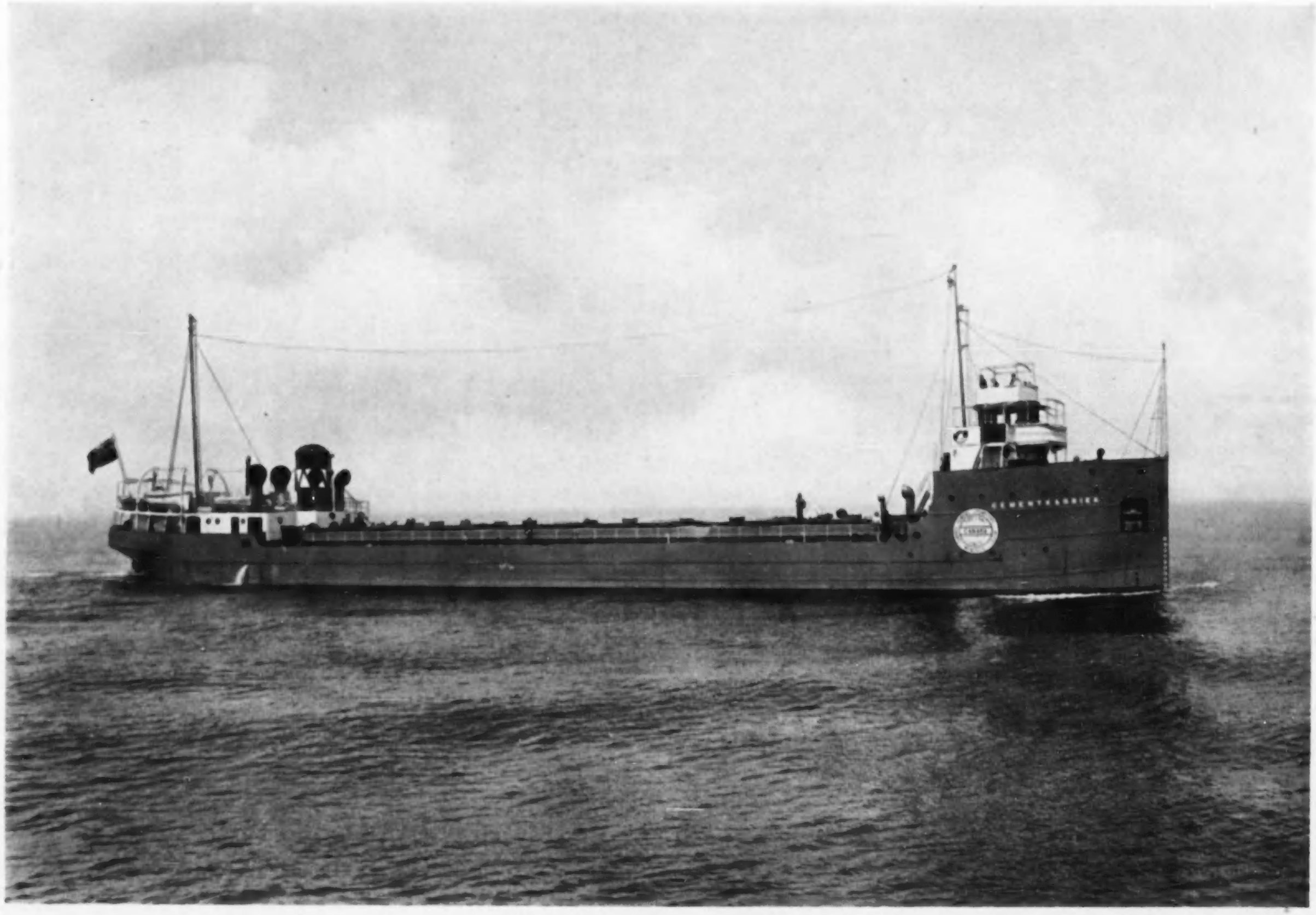
Copies can be obtained from the above address.



THE E.M.V. "CEMENTKARRIER."

The first vessel to be launched in Great Britain with both Diesel-electric propulsion and electrical self-discharging equipment.

G.E.C. Journal

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Diesel-electric Propulsion of the E.M.V. "Cementkarrier."

By C. WALLACE SAUNDERS, A.M.I.Mar.E., A.M.I.C.E., A.M.I.E.E., Marine Dept.,
and
S. A. G. EMMS, B.Sc., Switchgear Dept., G.E.C. Witton Engineering Works.

THE modern tendency towards Diesel-electric propulsion of ships is in no small measure due to the great reliability which electrically driven auxiliaries have been found to possess, a reliability which at once indicated the value of the electric drive for main propulsive purposes. In addition to its undoubted reliability, the electric drive has everything to offer in the way of robustness, low maintenance costs, flexibility and rapid manœuvring characteristics.

Recent developments in the design of high speed Diesel engines have also enabled certain difficulties hitherto experienced in electric propulsion to be overcome, and the development has now reached the promising stage at which marine superintendent engineers are prepared to accept the Diesel-electric drive. It must be pointed out, however, that each individual case requires careful consideration to determine whether circumstances oppose or justify the use of this form of propulsion; but, in the main, provided that a good design of Diesel engine is chosen, Diesel-electric propulsion will very quickly prove its efficiency.

The type of non-reversible Diesel engine now used in conjunction with electric propulsion has a great advantage over the direct drive, slow speed reversible engine by reason of (*a*) its high constant speed and consequent lighter reciprocating parts, (*b*) the elimination of complicated reversing gear and (*c*) the better distribution of weight in the ship with its attendant reduction in vibration.

This simplified design of constant speed Diesel engine has enabled designers to develop units having low fuel consumption and low maintenance cost. One particular advantage is the very small space required for overhaul, thus allowing complete decks to be built right through the ship, giving additional accommodation, or cargo space, and thereby increasing the earning capacity of the ship.

It is largely due to Mr. W. F. Fletcher of Montreal, the naval architect, that the electrically propelled E.M.V. "Cementkarrier," one of the most interesting vessels yet constructed for the bulk handling of cargoes, is now afloat and has recently completed her maiden voyage across the Atlantic under her own power. The "Cementkarrier" was built at Haverton Hill-on-Tees, by the Furness Shipbuilding Co., Ltd., to the order of The Canada Cement Transport Co., Ltd., for the carriage of powdered cement in bulk on the Canadian Great Lakes.

It should be noted that she is the first electrical self-discharging vessel laid down in this country, the particular features of interest being in the Diesel-electric propelling machinery and the electrical cement discharging gear.

Some idea of the close manœuvring demanded from a vessel plying on these lakes may be gained from the tact that there are between Montreal and Lake Ontario some six canals and twenty-one locks, while between Lake Ontario and Lake Erie, the connecting link of which is the Welland Canal, there are no less than twenty-five locks. Conditions of operation are such that a ship must check way immediately on entering these locks. This can only be accomplished by means of the most reliable manœuvring arrangements, and the inability of the early electrically propelled ships

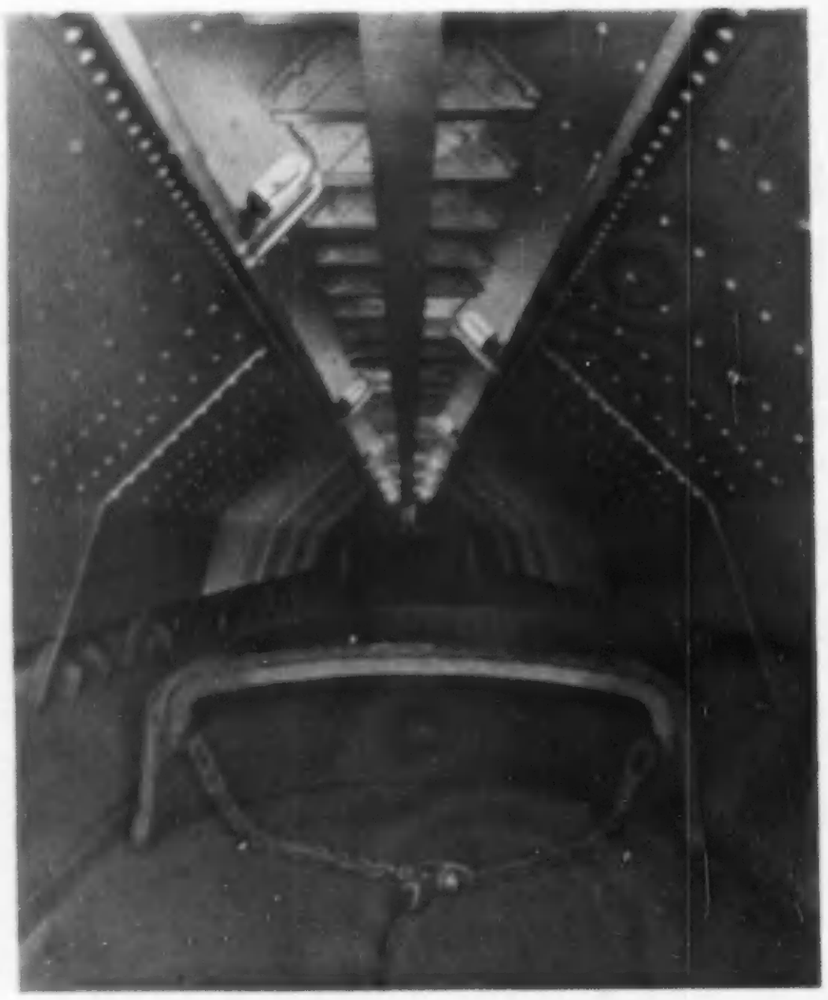

Fig. 1.—Sauerman scraper in scraper tunnel.

to withstand these admittedly gruelling conditions was responsible for the unpopularity of Diesel-electric drives, a stigma which has only within the last year or so been removed. The "Cementkarrier's" normal run is on Lake Ontario between the ports of Toronto and Belville, which is on the north shore of Quinte Bay, at the mouth of the Moira River.

The principle dimensions of the vessel are :—

Length	258 ft.
Beam	43 ft. 2 ins.
Moulded depth	20 ft.
Total dead weight	3,150 tons (approx.)

The first three items in the above list are ordinary Great Lakes Canaller dimensions. Cargo space is all amidships and the self-unloading gear right forward, while accommodation for the crew and navigating officers is also forward on the main deck in the bluff bows of the ship. Engineers' quarters are aft close to the engine room.

CARGO HANDLING.

It will be appreciated that very special precautions have to be taken to guard against leakage of water into the cement cargo. A double skin is therefore fitted on each side of the cargo holds in addition to wing tanks and cellular double bottoms to the holds. Watertight steel covers are also fitted to the cargo hatches.

The cement cargo is delivered into the holds by means of shore pipes led into small watertight steel access hatches fitted on the trunk top into three self-trimming holds of hopper formation, each of which is divided by steel centre line bulkheads into two compartments so arranged as to deliver cargo into two fore and aft scraper tunnels.

The discharging gear consists essentially of a Sauerman scraper (fig. 1) of 4 cubic yards capacity, situated in each scraper tunnel, and supported from a traveller which runs on an overhead trackway. The scraper is hauled along the tunnels by special steel wires led to two electric haulages which drag the scrapers along the tunnels up an inclined path and discharge the cement into a hopper bunker. This in turn feeds through a sliding gate into the archimedean screw of a high speed Fuller-Kenyon cement pump, fig. 2, driven by a 300 h.p. motor. The cement is then blown and pumped overboard through an 8 in. pipe discharge line by the cement pump and two Reavell air compressors, each electrically driven by a 208 h.p. motor, fig. 3. The

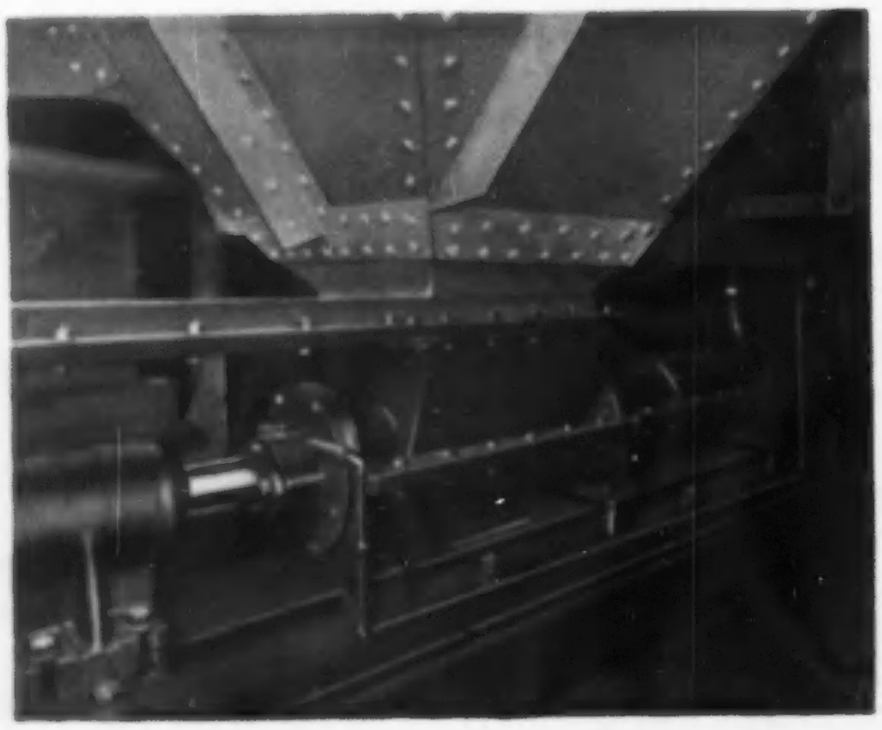

Fig. 2.—High speed cement pump.

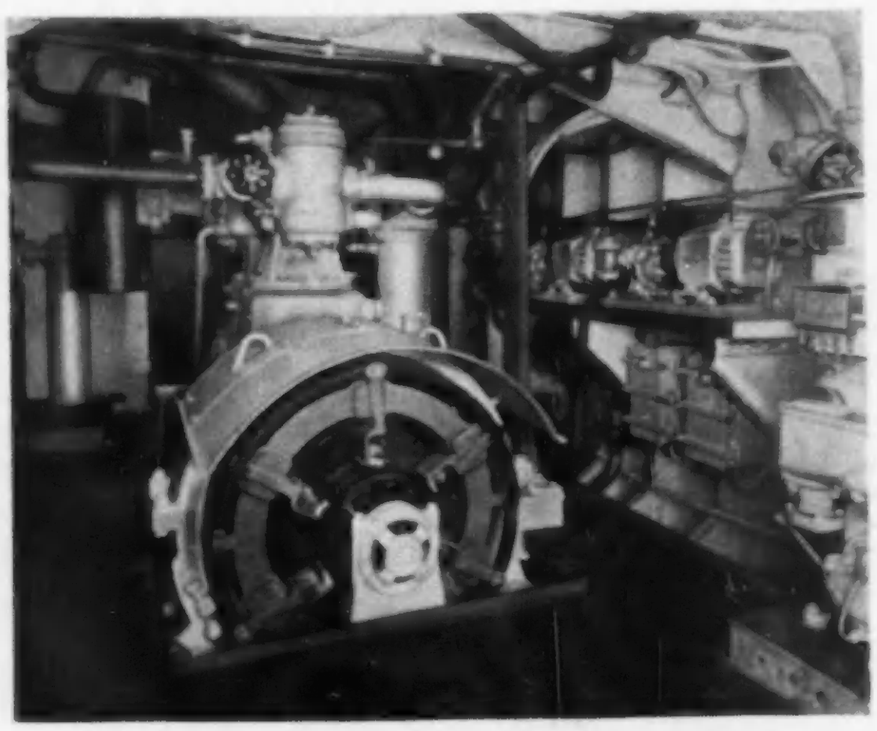

Fig. 3.—One of the two electrically driven air compressors.

haulages and pumps are installed in a separate compartment at the fore end of the vessel.

The total capacity of the hold is 2,300 tons, and discharge of the cargo can be completed in the relatively short time of four hours. Indeed, so rapid is the discharge that, in accordance with the general practice of Great Lakes Ships, automatic electric mooring winches are fitted together with an electric snubbing winch with wire compressor.

It will thus be seen that during discharge, electric power is required for two 208 h.p. motors for the air compressors, one 300 h.p. motor for the screw pump, two 100 h.p. motors for the scraper winches and four 18 h.p. motors for the automatic winches on deck. The winches will be in operation during part of the time of unloading as the ship will be rising out of the water so quickly with the rapid rate of discharge that constant hauling in will be necessary. Assuming that only one compressor motor operates at a time, it is quite possible that a total auxiliary load of 780 h.p. is intermittently taken from the generators installed in the engine room.

8328-20

Fig. 5.—View down centre of engine room looking between the two Diesel engines.

By virtue of these cargo handling arrangements the auxiliary load is at times higher than the main propelling load. On such occasions the output of the generator sets is in excess of that required for main propulsive purposes.

This fact provides the ideal case for Diesel-electric propulsion for, obviously, if sufficient generating plant is to be installed in a ship to enable her to self-discharge her cargo, and if the total power so required is equal to, or in excess of, that needed for propelling the vessel through the water, then the same source of power may economically be used for propulsion, especially as the two loads are never simultaneous.

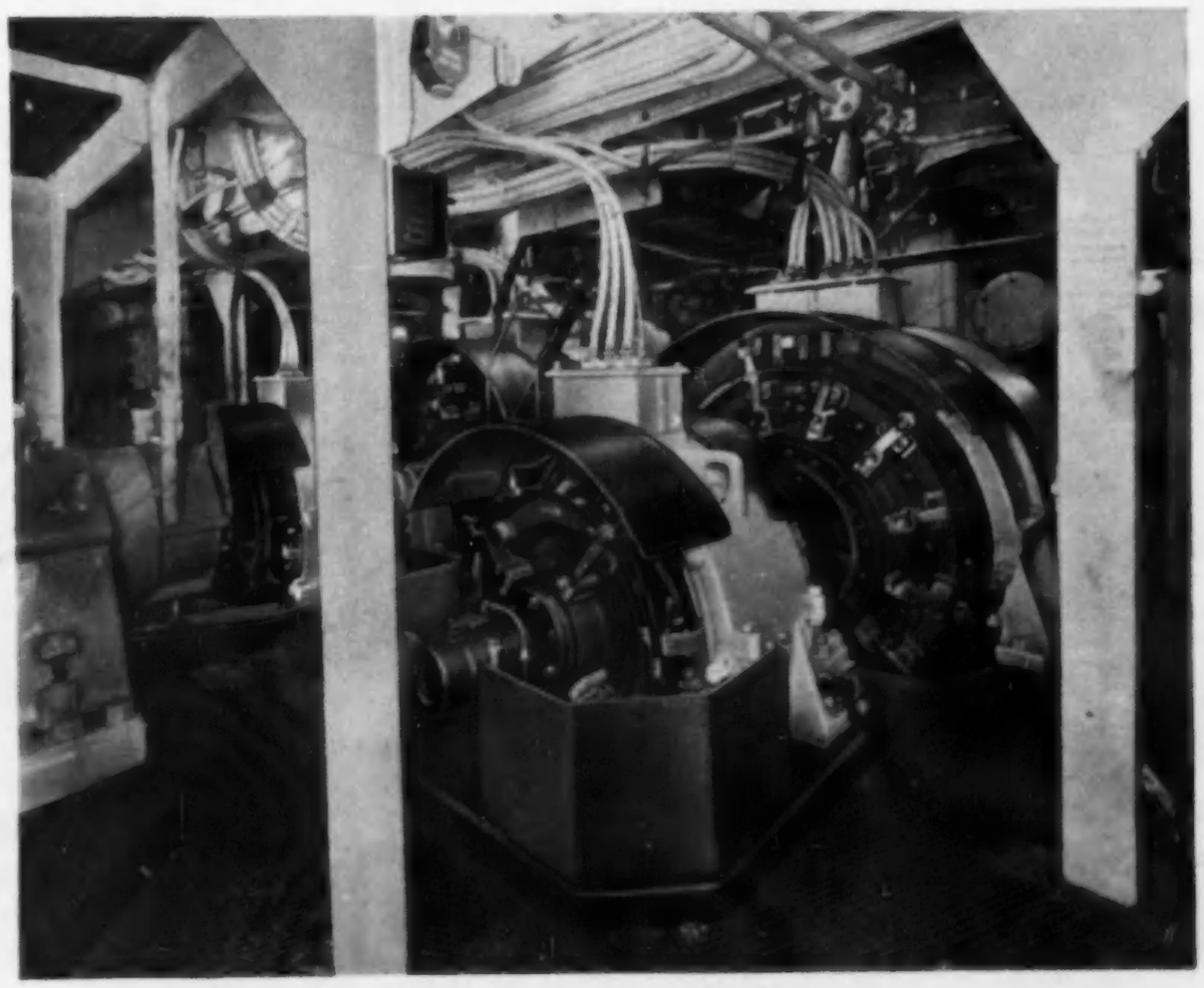

Fig. 4.—Engine room, showing two main generators, each with auxiliary generator coupled in tandem.

ELECTRICAL EQUIPMENT.

The electrical propelling machinery, all of which was manufactured and supplied by The General Electric Co., Ltd., comprises the following equipment :—

Two 360 kW direct current main generators, each direct coupled to a 500 h.p. Atlas Diesel-engine running at 220 r.p.m., fig. 4.

Two 50 kW auxiliary direct current generators, one coupled in tandem to each of the main generators.

The main propulsion motor, rated at 775 h.p. at 100 r.p.m. This double armature machine is illustrated in fig. 6.

Two 30 kW emergency sets, fig 7, consisting of Petter "Atomic" Diesel engines driving compound wound generators. These emergency sets may also be run in parallel with the 50 kW auxiliary generators.

The main switchboard, fig. 8, consisting of fourteen panels controlling the main generators, auxiliary and emergency generators, lighting and engine room auxiliaries, feeders and emergency circuits, main motor field contactors and switches and compressor motor circuits. There are also two selector panels and a main circuit breaker panel for controlling the supply to the forward switchboard which consists of two panels controlling the discharge pumps and the two scrapers.

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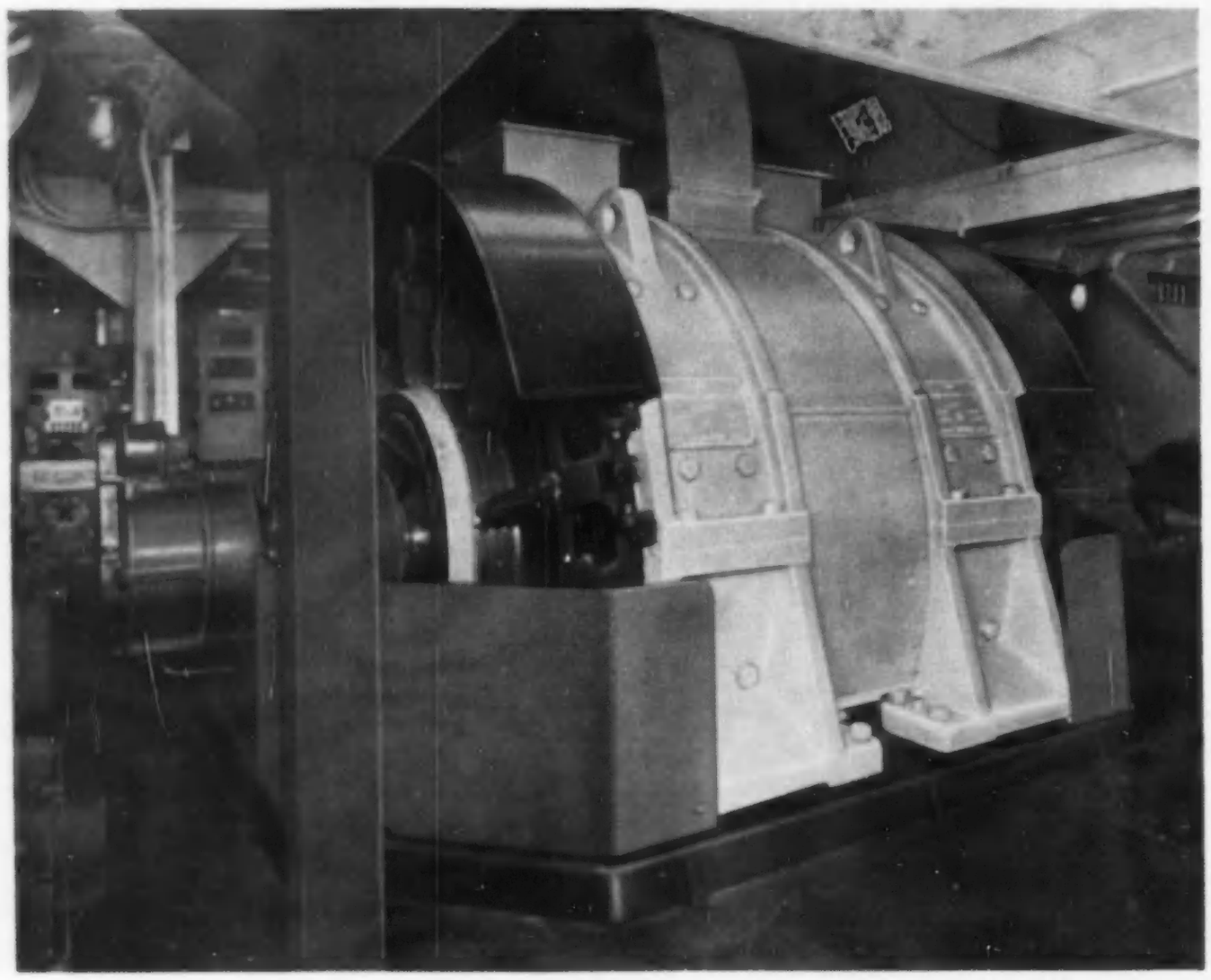


Fig. 6.—775 h.p. double armature propeller motor.

ENGINE ROOM LAYOUT.

The engine room occupies the extreme after part of the ship, and the propulsion motor drives a short tail-shaft through a Mitchell thrust block. Forward of the motor are the port and starboard main engines, each driving one main and one auxiliary generator in tandem, while outside the main sets are mounted the two air compressor sets with their 208 h.p. driving motors. In the wings of the engine room, at the forward end, are the two 30 kW emergency generator sets.

The engine room auxiliaries are installed against the ship's sides, and include pumps for ballast, general service, bilge, lubrication and fuel oil, circulating water, cooling water, and sanitary purposes. These pumps are driven by vertical spindle motors, and are controlled by hand-operated or automatic marine-type starters.

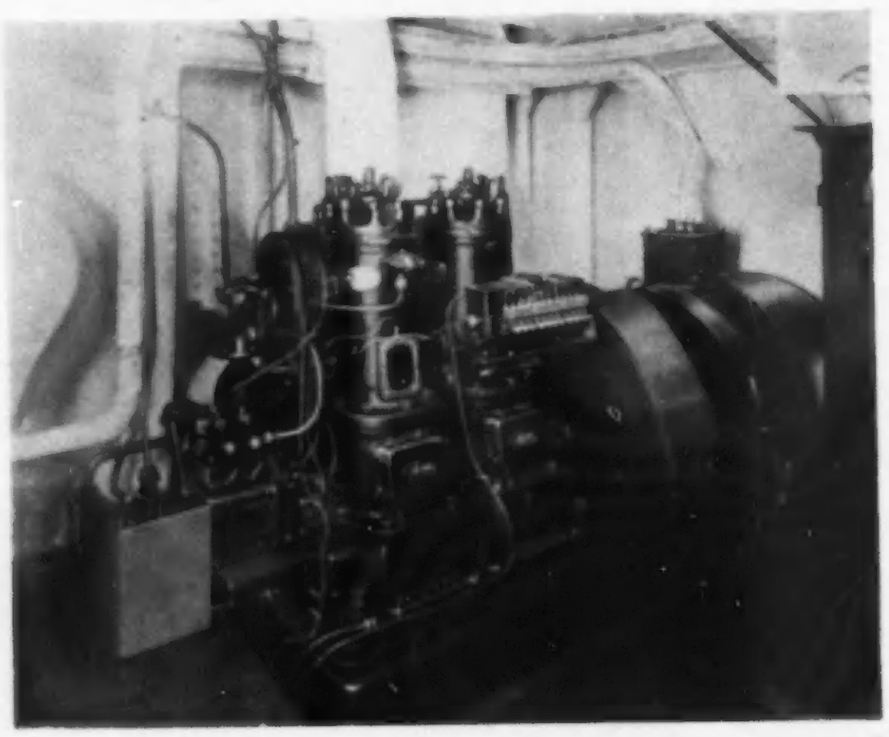


Fig. 7.—30 kW oil-engine driven emergency generator.

The main switchboard is mounted athwartships on a flat at the level of the top main engine platform, above and slightly forward of the propeller motor. At the after end of this flat, on the starboard side, is situated the ventilating fan for the main motor.

The control platform is on the same flat at the starboard side, and has the usual bridge telegraph, together with the automatic speed-control pillar.

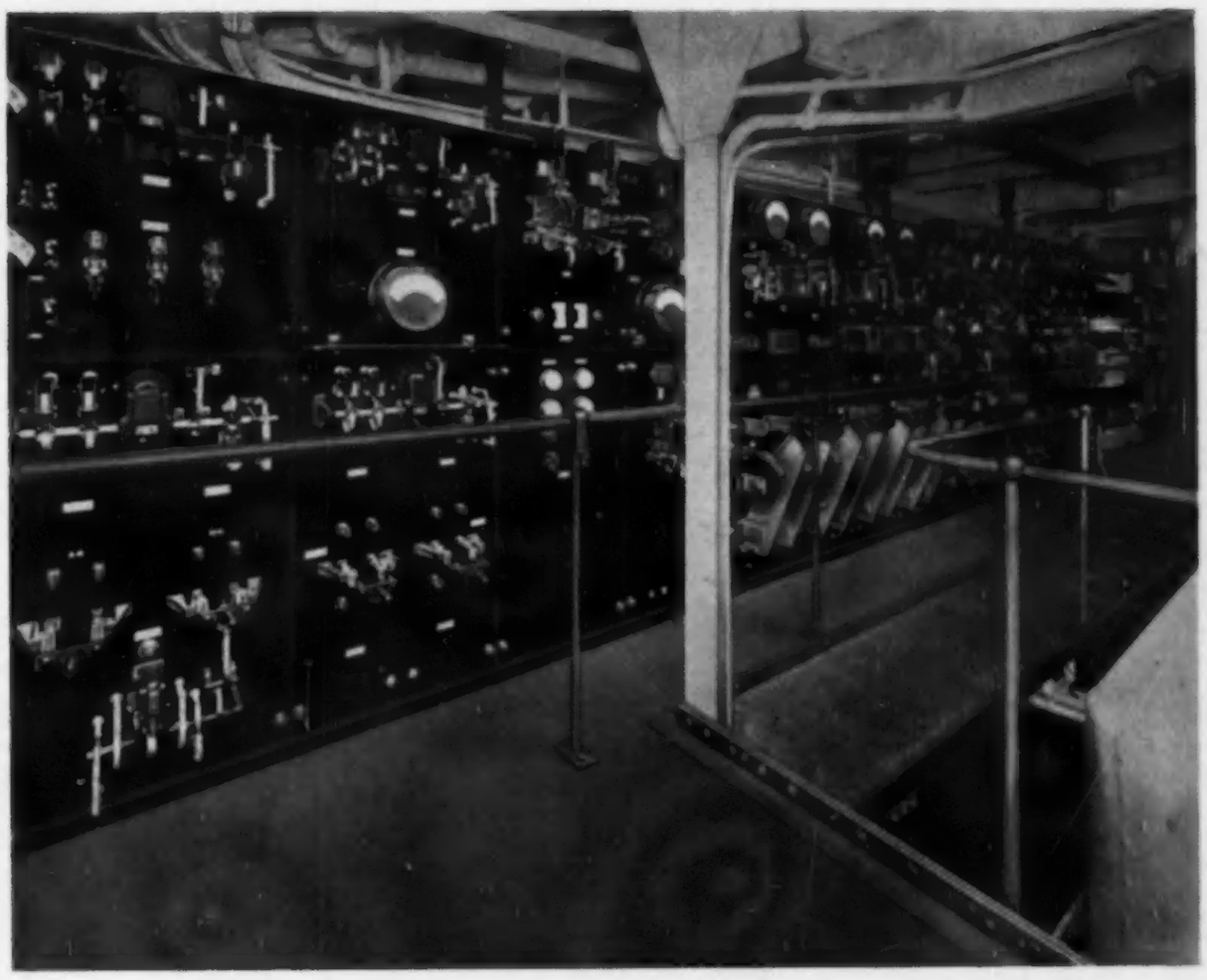


Fig. 8.—Main switchboard.

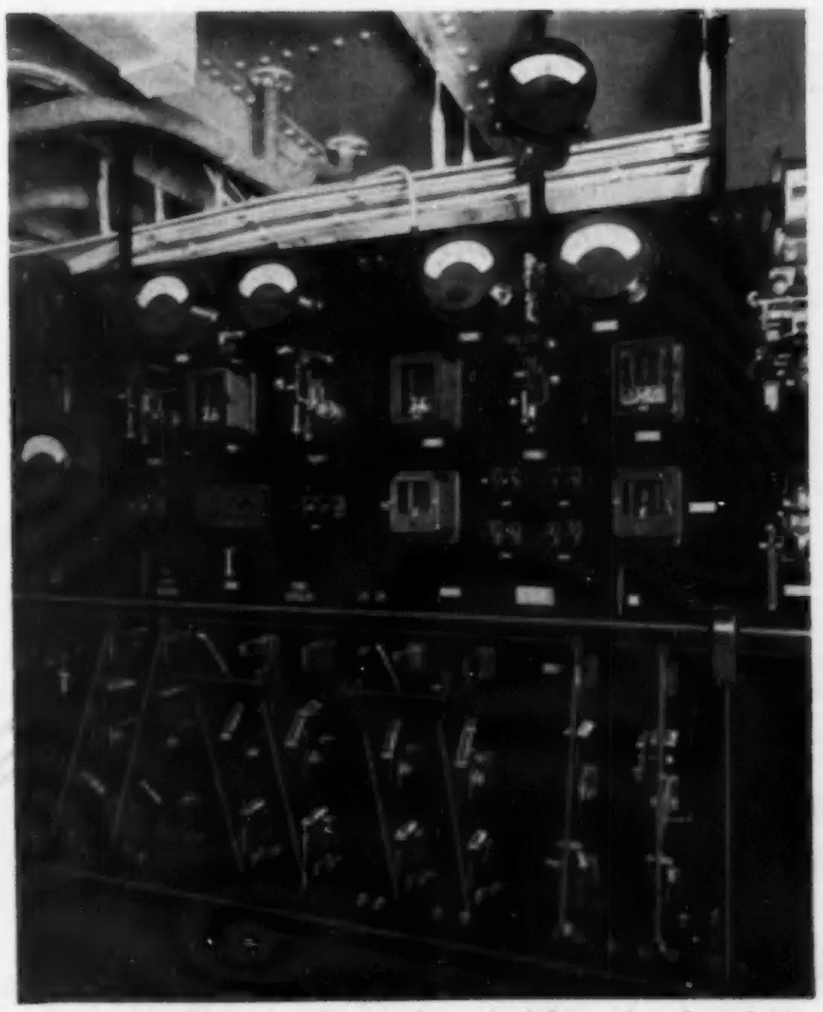


Fig. 9.—Detail view of switchboard, showing balanced-voltage, over-power and bridge control relays; also main change-over knife switches.

The main field regulator is also mounted here, and is provided with a hinged panel giving access to the handwheel for emergency operation.

DIESEL ENGINES.

Both of the main generators are driven by Atlas Diesel engines rated at 500 h.p. when running at 220 r.p.m. The engines are of the latest 2-cycle airless injection type. The cylinders, which are of "monobloc" construction fitted with liners, are secured to the bedplate by long tie bolts extending from near the cylinder heads right through to the underside of the bedplate, thus relieving the castings of all tensile stresses. Each engine has four cylinders, the dimensions of which are 340 m/m bore by 570 m/m stroke.

The engines are mounted on special bedplates extended to carry the generators. In order to shorten the overall length, the flywheels are mounted on the generator coupling flanges. Direct driven water circulating pumps are fitted, and compressed air for starting is provided by a motor driven air compressor. For emergency use, an auxiliary air compressor is installed, driven by a 6 b.h.p. crude oil engine which is easily started by hand.

PROPULSION EQUIPMENT.

The propeller motor is of the double armature type rated at 775 h.p., and is direct coupled to the propeller shaft which it drives at a maximum speed of 100 r.p.m. The output required from each main generator for the propeller motor on full load is 320 kW., and the balance of power from the engines is utilised for the 50 kW auxiliary generators which supply the engine room auxiliary load. When

the ship is in port the main generators run as compound wound machines operating in parallel to supply the cargo handling machinery which may demand power up to their maximum output of 360 kW each.

The main drive is on the Ward-Leonard principle, the generator fields being controlled by motor-driven field regulators.

catch holds up the movement of the change-over switches. This hold up of movement allows sufficient time for the field flux to die down before the change-over switch temporarily short circuits the armature, thus preventing the generation of heavy currents during the short circuit.

With the arrangement adopted the following running combinations are possible, and may be brought

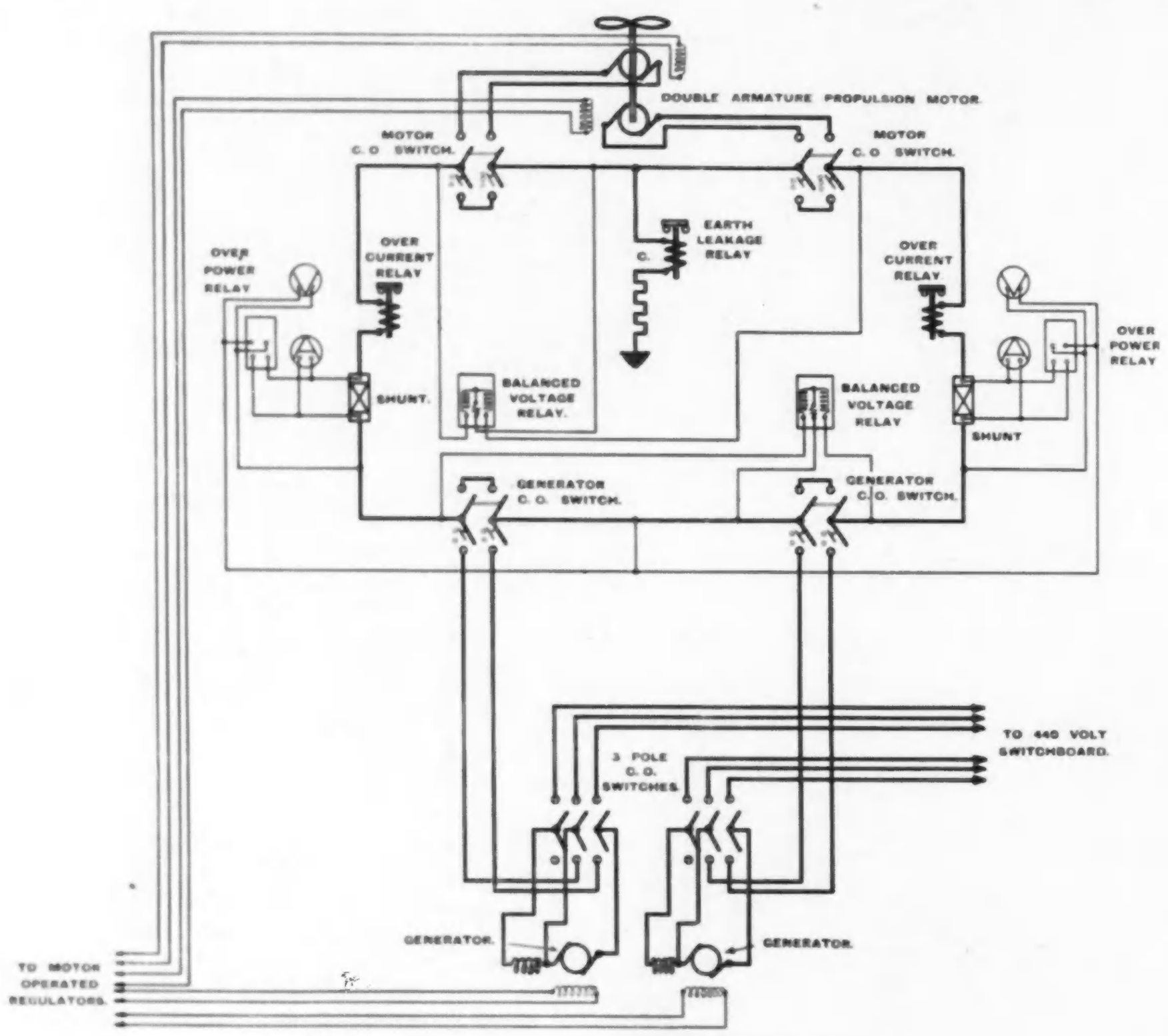


Fig. 10.—Schematic diagram of main propulsion circuits.

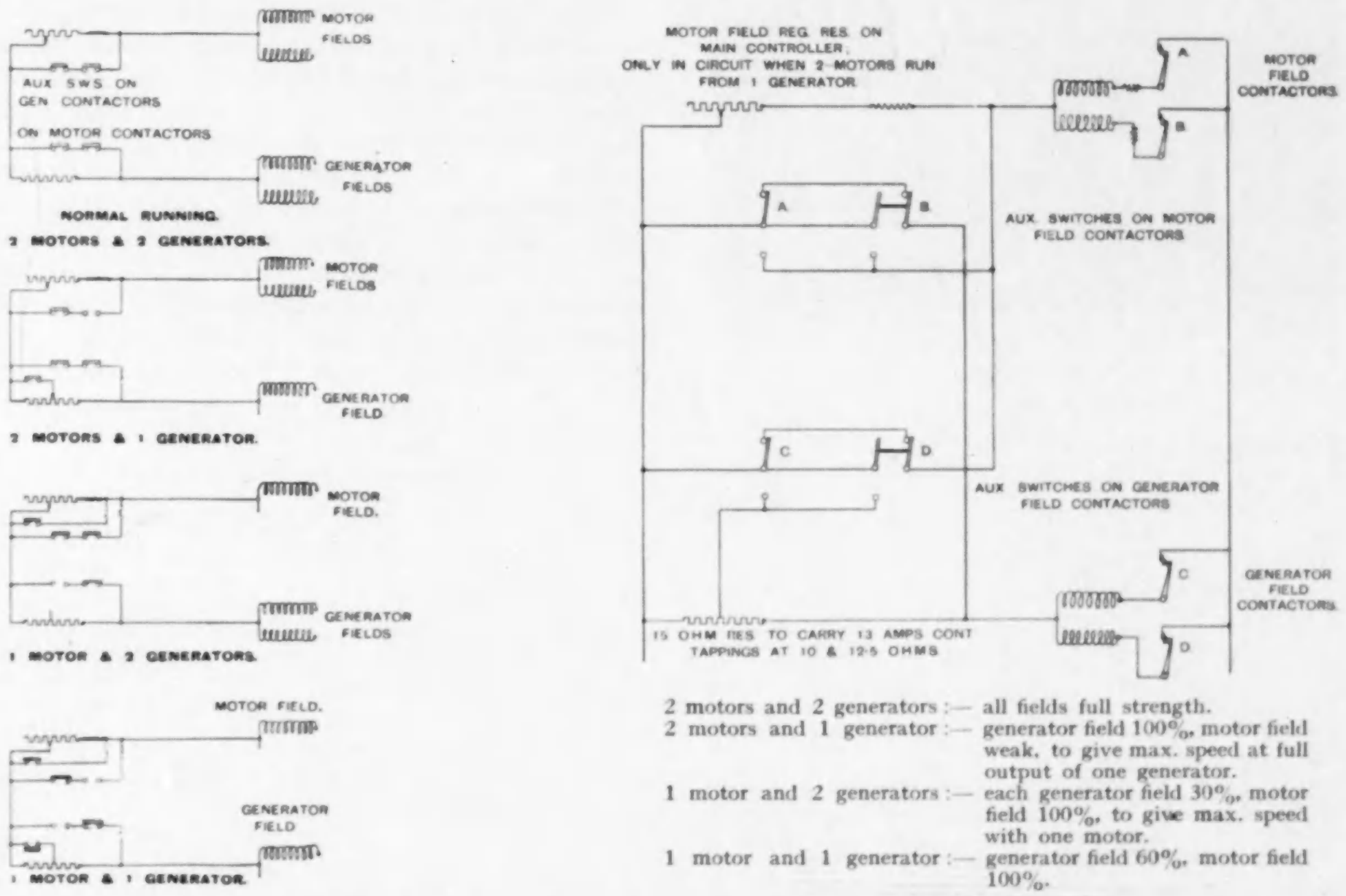
It will be seen from fig. 10 that the double armature propulsion motor and the two main generators form a single series circuit, earthed between the motor armatures. Change-over switches connect the main generators either to the propulsion circuit or to the 440 volt cargo-handling busbars, while any of the four machines may be completely cut out of circuit in the event of a fault. The large knife switches which effect these changes are to be seen in the centre panels of the switchboard, fig. 9. The operation of a cut-out switch automatically isolates the corresponding field, and a sequence about either manually, as described above, or automatically through the tripping of protective relays.

1. Both motors and both generators (Normal).
2. Both motors and either generator.
3. Either motor and both generators.
4. Either motor and either generator.

As with combinations 2, 3 and 4, reduced power only is available, the fields of the sound machines have to be adjusted so as to give a suitable lower propeller speed (about 81 per cent. since the power varies approximately as the cube of the speed). Each field is controlled by a contactor, and fig. 11

shows how the opening of any of these contactors introduces the necessary compensating resistances. These contactors are provided with auxiliary contacts, which when open, automatically insert suitable resistances in either the motor or generator field circuits in order to adjust the operating conditions to the new combination of machines left in circuit. This procedure, in conjunction with special balancing relays, avoids the necessity of shutting down the propulsion motor when the number of machines in circuit is altered either deliberately by hand, or automatically in emergency through machine failure. The operation of the change-over selector switches also indicates, by means of pilot lamps on a panel mounted on the bridge, exactly which machines are in service for propulsion purposes.

The main rheostat, which is adapted for hand or automatic operation, energises all field contactors, varies and reverses the generator fields, and (in case 2) introduces the necessary field weakening resistance into the circuit of the motor.


MOTOR FIELDS
AUX SWS ON GEN CONTACTORS
ON MOTOR CONTACTORS
GENERATOR FIELDS
NORMAL RUNNING.
2 MOTORS & 2 GENERATORS.
MOTOR FIELDS
GENERATOR FIELD
2 MOTORS & 1 GENERATOR.
MOTOR FIELD.
GENERATOR FIELDS
1 MOTOR & 2 GENERATORS.
MOTOR FIELD.
GENERATOR FIELD
1 MOTOR & 1 GENERATOR.
MOTOR FIELD REG. RES. ON MAIN CONTROLLER; ONLY IN CIRCUIT WHEN 2 MOTORS RUN FROM 1 GENERATOR.
A
B
MOTOR FIELD CONTACTORS.
AUX. SWITCHES ON MOTOR FIELD CONTACTORS.
C
D
AUX. SWITCHES ON GENERATOR FIELD CONTACTORS.
GENERATOR FIELD CONTACTORS.
15 OHM RES. TO CARRY 13 AMPS CONT. TAPPINGS AT 10 & 12·5 OHMS.

2 motors and 2 generators :— all fields full strength.
2 motors and 1 generator :— generator field 100%, motor field weak, to give max. speed at full output of one generator.
1 motor and 2 generators :— each generator field 30%, motor field 100%, to give max. speed with one motor.
1 motor and 1 generator :— generator field 60%, motor field 100%.

Fig. 11.—Method of inserting resistances as machines are cut out.

AUXILIARY SUPPLY.

The auxiliary 220-volt supply for power and lighting is furnished by two 50 kW generators in tandem with the main machines. These auxiliary generators, which furnish power for pumps, winches, windlass, steering gear, etc., are controlled by two panels on the main switchboard, at the port side. As the speeds of the main sets are likely to vary and differ in service, the panels carry Brown Boveri automatic voltage regulators, in addition to the ordinary equipment of circuit breaker, equaliser switch, field rheostat and voltmeter plug.

In emergency, or in port, when the main engines are not running, the auxiliary supply is obtained from either or both of the 30 kW sets, the control panels of which are situated next to those of the auxiliary generators.

EXCITATION SUPPLY.

The generator fields and steering gear are supplied from special 220-volt auxiliary busbars connected through an automatic change-over contactor to the main 220-volt bars which derive their supply from the 50 kW generators. To the special auxiliary busbars are also connected emergency circuits.

EMERGENCY BATTERY.

Should the main 220-volt supply fail, the automatic contactor switches the special auxiliary busbar over to the emergency battery discharge busbars. At the same time a bell and lamp on the switchboard inform the engineer of the failure. The capacity

of the emergency battery is 110 ampere-hours at 220 volts.

Supply is thus maintained until the emergency generator can be run up, when the contactors automatically switch the special auxiliary bars back to the main supply.

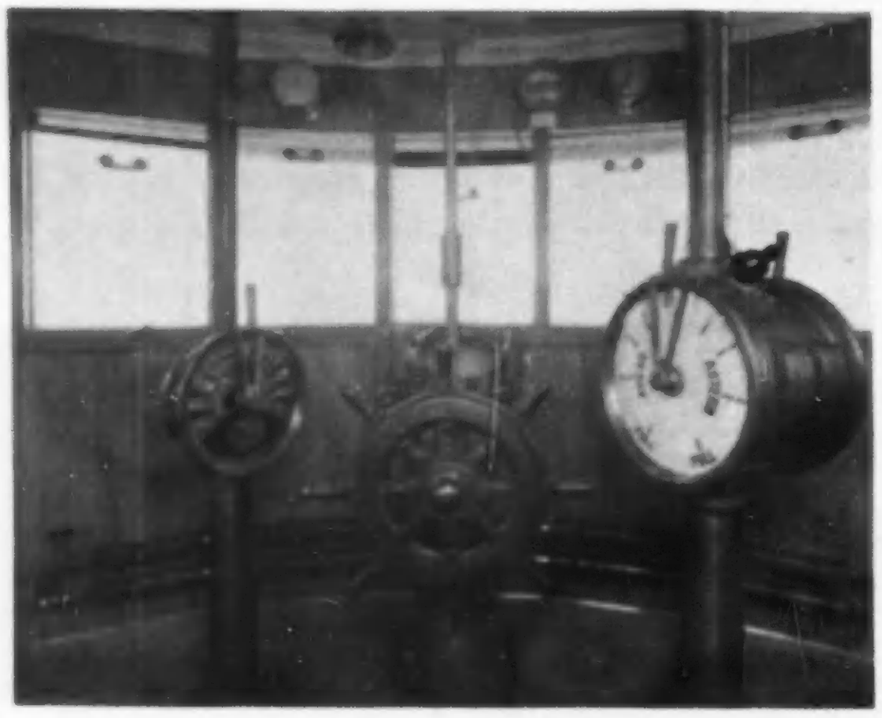


Fig. 12.—View in wheelhouse showing control gear.

SPEED CONTROL.

Four control positions are provided and these are situated :—

1. In the wheelhouse, fig. 12.
2. On the flying bridge.
3. In the engine room.
4. In the engine room (manual control).

At the first three positions, control pillars exactly similar to standard ships bridge telegraphs, are installed, a practice which is general in Diesel-electric ships as it has the psychological effect of taking away from the shipmaster the strangeness of actually controlling the propeller himself.

The bridge and flying bridge pillars are mechanically coupled, and in case of necessity, such as a breakdown in the cabling between the bridge and engine room, the engineer can take control on No. 3 by throwing over a switch which automatically cuts out the bridge control. The engineer then takes orders by standard telegraph or telephone from the bridge. Should the electric control become inoperative, the engineer can open a door in the regulator itself, exposing a handwheel for manual operation, the action of opening the door automatically making the change-over. A system of visual and audible signals is provided between the bridge and the engine room, to indicate when control is transferred from one to the other, and the navigating officer or the engineer, as the case may be, must acknowledge the signals by moving a switch in the wheelhouse to correspond with that in the engine room.

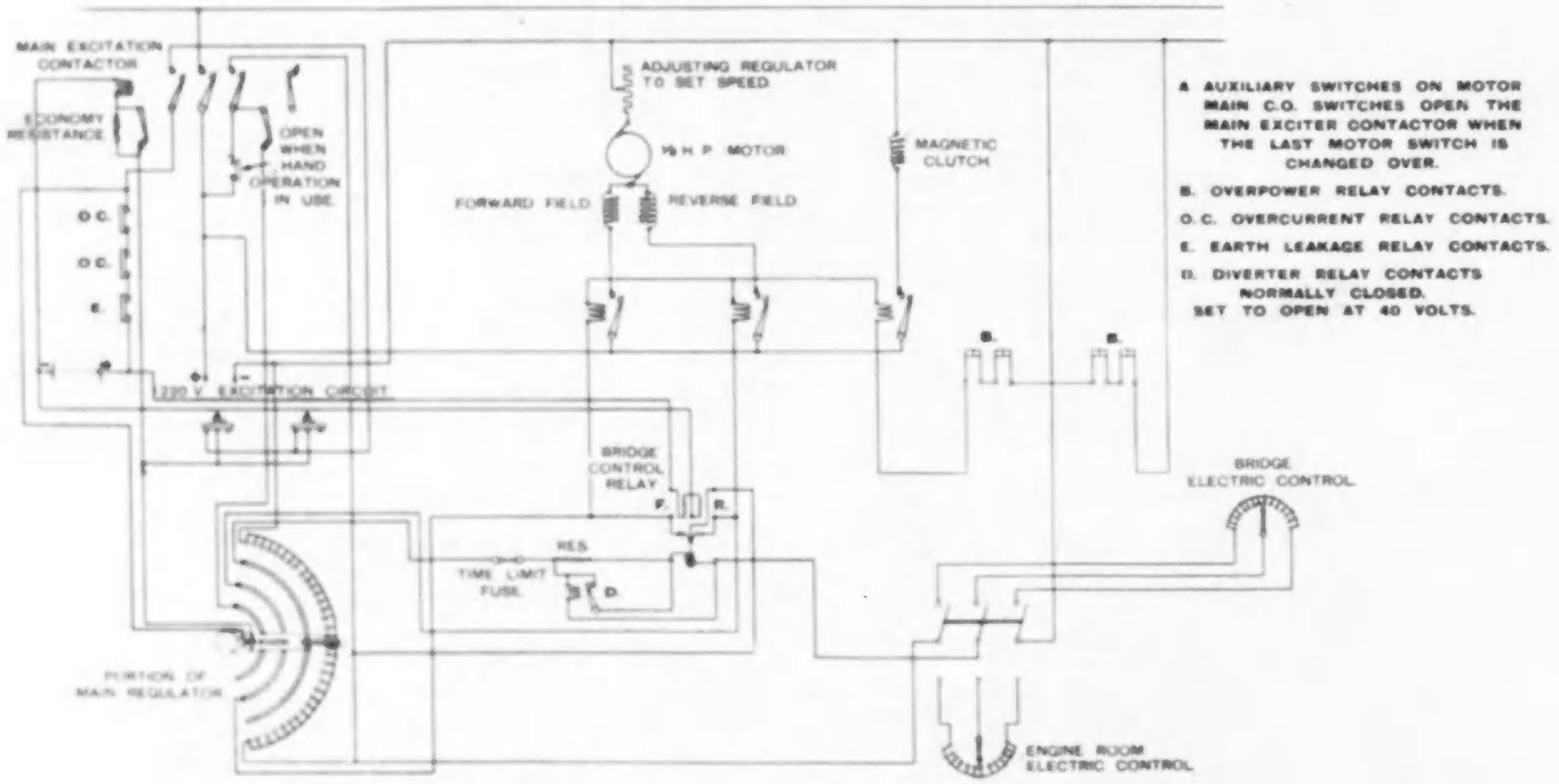


Fig. 13.—Main excitation and bridge control circuit.

From the busbars the field supply passes through a single pole main excitation contactor, and thence to the field contactors of the individual machines. The over-current and earth relay contacts are connected in the holding circuit of this contactor, which, once tripped, cannot be re-set until the main rheostat has been returned to the "off" position.

FOLLOW-UP GEAR.

The follow-up gear, by means of which the position of the main regulator is made to correspond exactly with that of the control pillar on the starting platform or on the bridge, is of particular interest on account of the small number of control wires used, only three connections being required for control between the bridge and engine room. The apparatus employed is shown diagrammatically in. fig. 13. It will be seen that the principle is that of the Wheatstone Bridge, in which the galvanometer is replaced by a relay with two pairs of contacts, normally open.

Each control pillar contains an arm which makes contact with studs connected to a control resistance energised from the 220-volt battery. A similar resistance and contact arm is mounted in the main regulator, and it will be evident that as long as the rheostat and control pillar arms are in contact with corresponding resistance studs, no voltage will be impressed upon the relay. If the control pillar arm be now moved in either direction, a voltage corresponding exactly in direction and magnitude with the motion will be impressed on the relay which will then deflect and close one of its pairs of contacts.

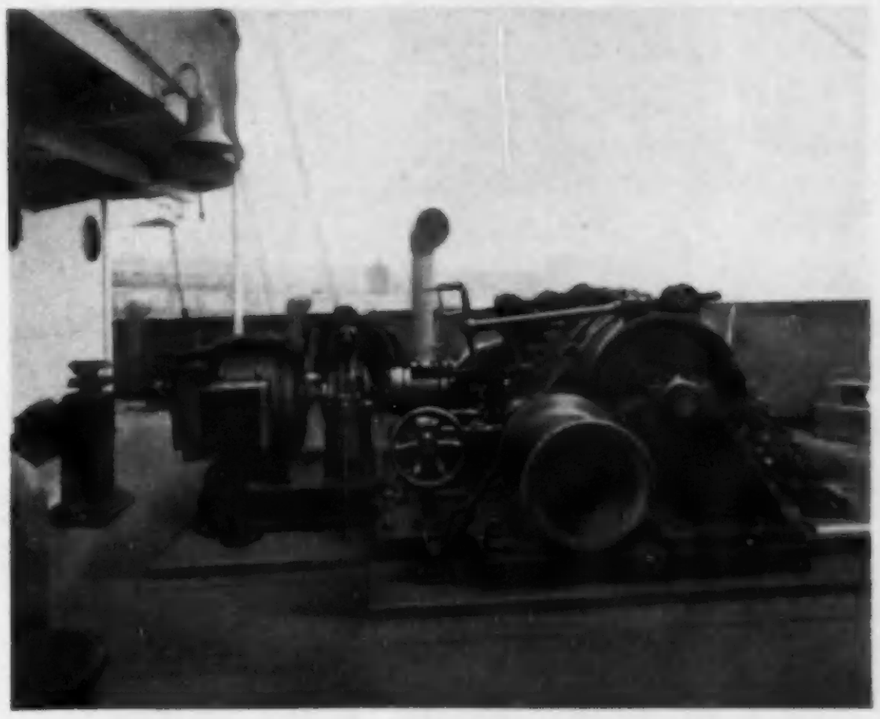


Fig. 15.—Electric anchor windlass.

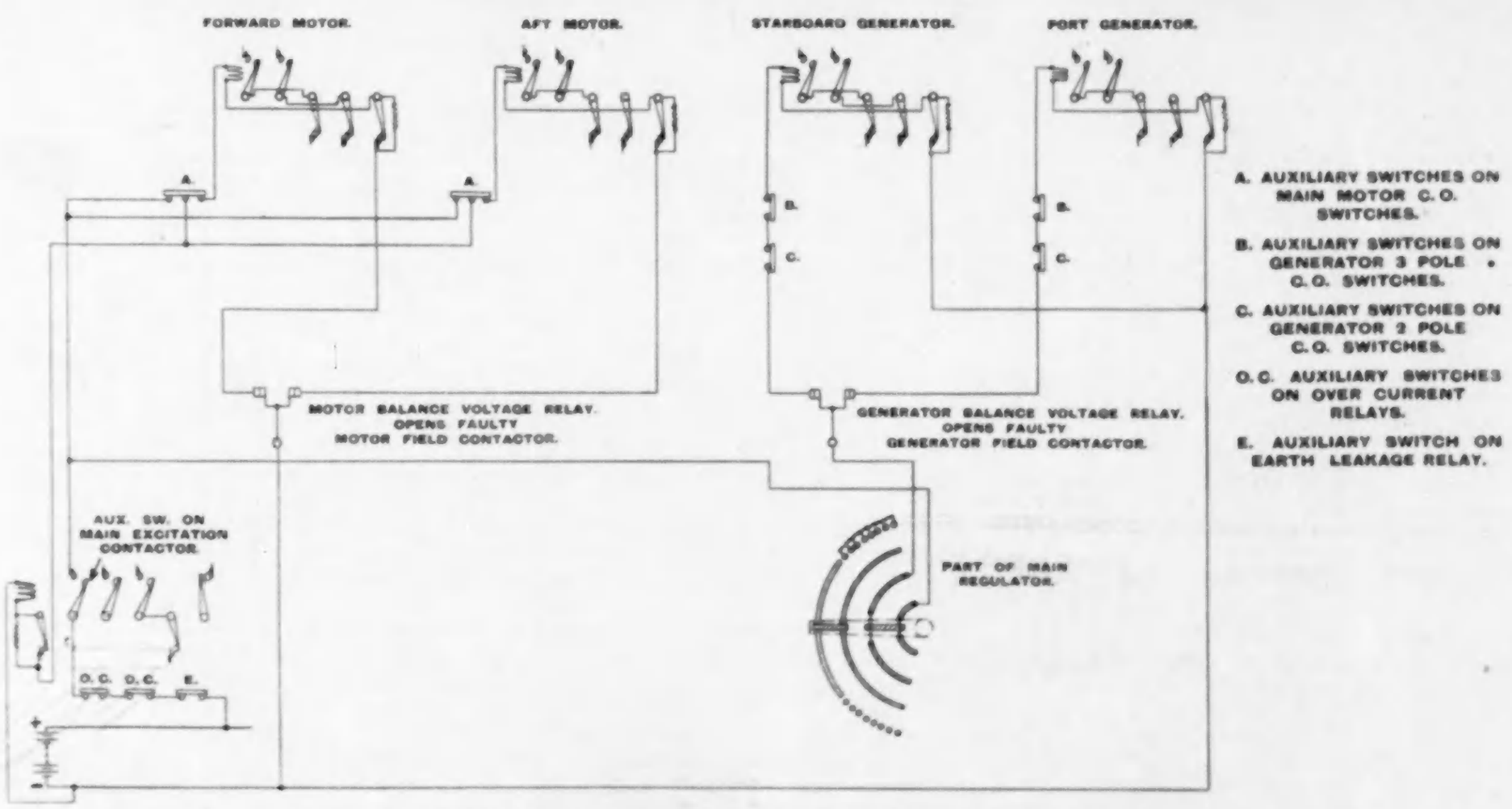

FORWARD MOTOR.
AFT MOTOR.
STARBOARD GENERATOR.
PORT GENERATOR.
A.
B.
C.
MOTOR BALANCE VOLTAGE RELAY. OPENS FAULTY MOTOR FIELD CONTACTOR.
GENERATOR BALANCE VOLTAGE RELAY. OPENS FAULTY GENERATOR FIELD CONTACTOR.
AUX. SW. ON MAIN EXCITATION CONTACTOR.
O.C. O.C. E.
PART OF MAIN REGULATOR.
A. AUXILIARY SWITCHES ON MAIN MOTOR C.O. SWITCHES.
B. AUXILIARY SWITCHES ON GENERATOR 3 POLE C.O. SWITCHES.
C. AUXILIARY SWITCHES ON GENERATOR 2 POLE C.O. SWITCHES.
O.C. AUXILIARY SWITCHES ON OVER CURRENT RELAYS.
E. AUXILIARY SWITCH ON EARTH LEAKAGE RELAY.

Fig. 14.—Diagram of generator and motor field contactor operating circuits.

These contacts complete the coil circuits of the contactors controlling the driving motor of the main rheostat. One contactor decides the direction of revolution of this motor, while the other energises a clutch connecting the motor to the rheostat arm. The arm accordingly moves in the direction indicated by the motion of the control pillar until the voltage across the relay falls to zero, and the relay opens its contacts and de-energises the two small contactors. The clutch contactor immediately releases the clutch, and thus eliminates any tendency of the rheostat arm to overshoot. A complete diagram illustrating this equipment is given in fig. 13.

It will be noticed in this figure that the circuit of the rheostat operating motor contactor returns through a pair of contactors marked "Over/reverse power relays." The operating circuits of these relays are also indicated in fig. 10. Their purpose is to limit the maximum power transfer between the main engine and the propeller in either direction, *i.e.*, to prevent overload of the prime movers during

acceleration, or overspeed during deceleration owing to motoring of the main generator. When functioning in either way their effect is to hold up operation

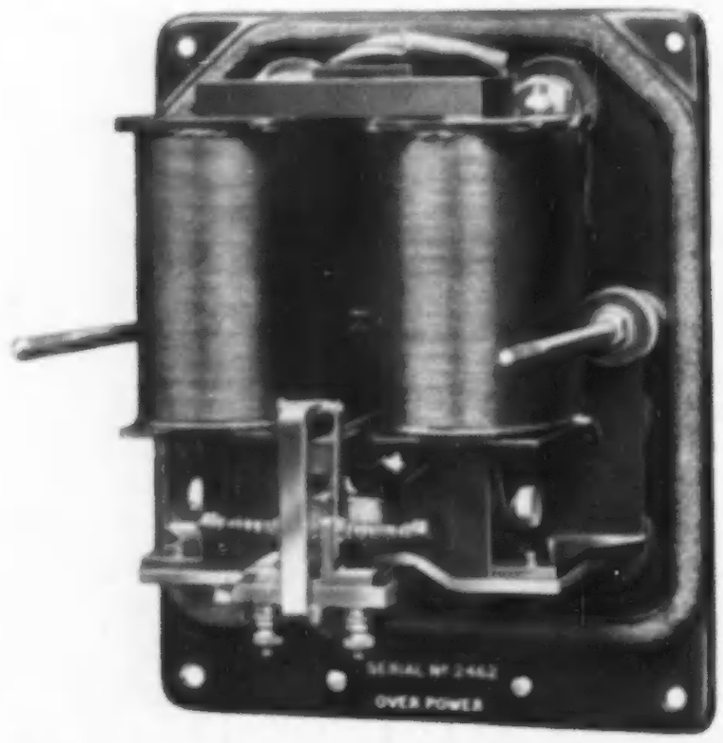


Fig. 16.—Over-power relay with cover removed.

of the main rheostat until the overload has decreased and the relays have re-set.

The over-power relay is shown in fig. 16, which, except for the arrangement of the contacts, is also representative of the relays for bridge control and balanced protection. They form a robust embodiment of the D'Arsonval principle, the simplicity of which is especially appropriate for marine work.

SAFETY AND PROTECTIVE DEVICES.

The entire excitation is supplied through a single contactor whose coil circuit may be broken by either of the current relays or the earth leakage relay. When the excitation contactors open, the connections are such that the main rheostat is immediately returned to the "off" position, and on re-closing, the rheostat returns to its original position.

Should a machine fail from any cause, the voltages of the two generators or the two halves of the motor would become different in value. This would cause the balanced voltage relays (fig. 14), to operate on one side or the other, causing the field contactors of the faulty machine to open. The opening of these contactors automatically inserts resistance in the various field circuits to adjust them to a suitable value for the new operating conditions.

The overload relays in the main circuit are provided with short time delays to give the balancing relays time to deal with faults which are not a permanent leakage to earth. Earth leakage faults

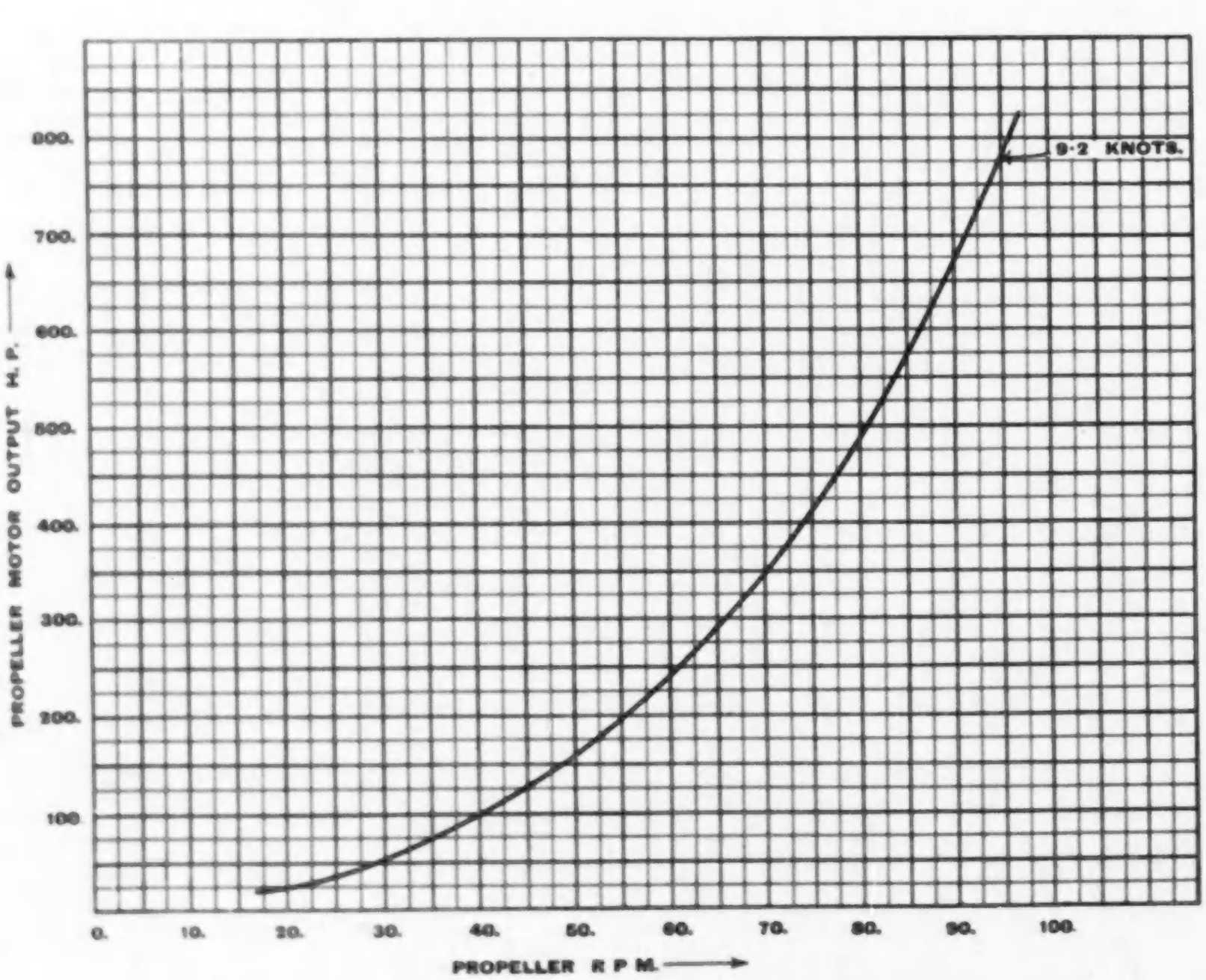


Fig. 17.—Relationship between propeller motor output and propeller speed.

operate the earth leakage relay and cut off all excitation. Persistent overloads, not cleared by the balanced voltage relays or the earth leakage, also shut off the whole of the excitation. After the balanced voltage relays have opened the field of a faulty machine, the engineer can at his early convenience, throw over the corresponding selector switch and isolate the armature of the faulty machine without interrupting the supply.

TRIAL RESULTS.

During the ship's trials both in dock and at sea, the electrical equipment functioned perfectly, the mean speed attained on the measured mile being 9.2 knots with the propeller motor developing 780 h.p. at 95 r.p.m. It should be mentioned that this motor drives a 4-bladed cast-iron screw 11ft. 6ins. in diameter, the normal load draught of the ship being 14ft., a figure which can be increased if necessary. Accurate readings of propeller speed and h.p. were taken for various speeds and the resulting curves are shown in fig. 17.

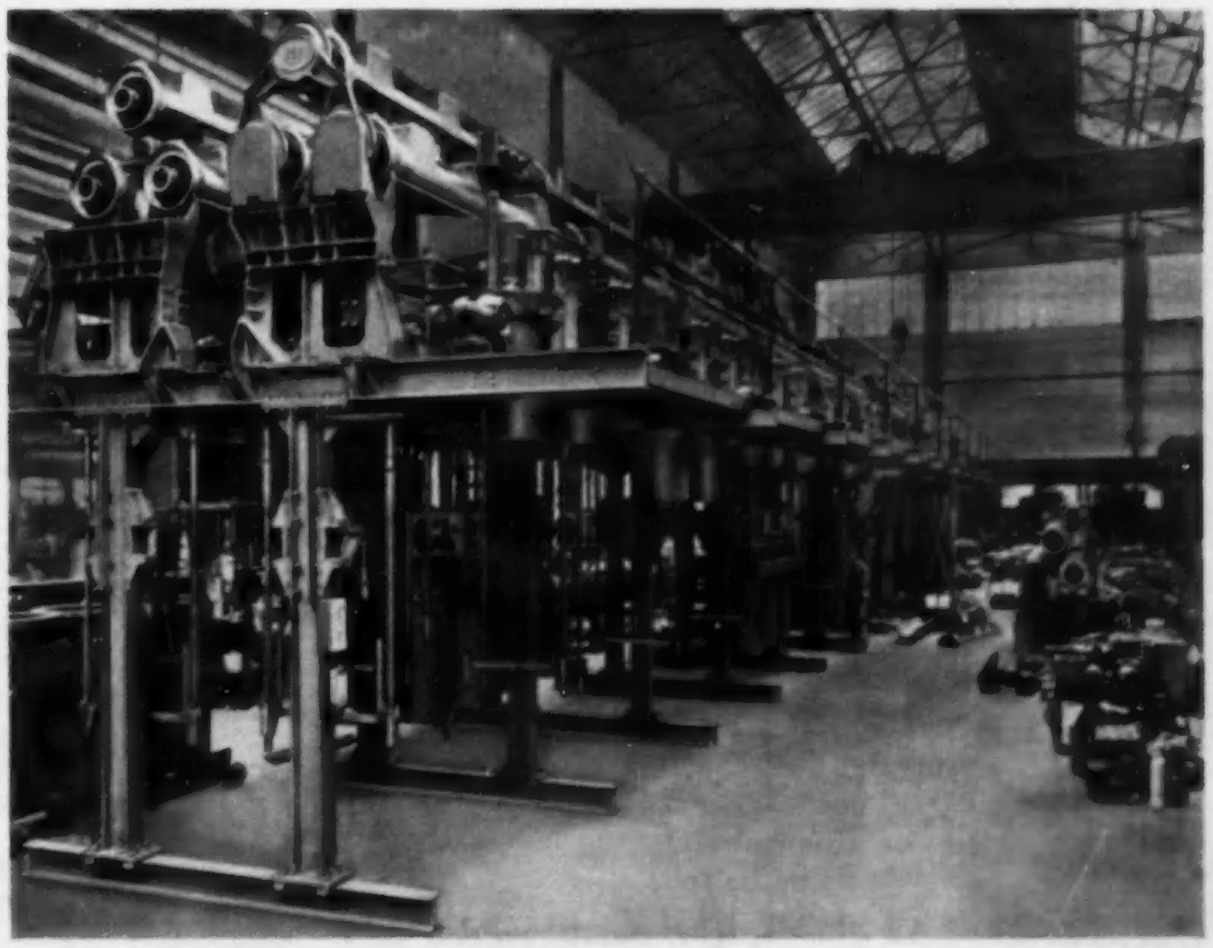
Manœuvring was carried out under both hand and automatic control from bridge and engine room. The change-over between these two positions, and between hand and automatic control, proved to be quick and easy in service. With the bridge control in use, the time of complete reversal (*i.e.*, full r.p.m. ahead to full r.p.m. astern) was approximately 16 seconds, and with the motor operated rheostat set for this period, the "feed-back" from the screw during retardation was very small. The reasons for this are probably to be found, firstly, in the full lines of the ship, the block coefficient of which is about .8 and, secondly, in her lightly laden state during trials, a condition which implies a higher ratio of resistance to energy of motion than would exist in normal practice. By a very rapid hand operation of the main rheostat a momentary "feed-back" of about 150 h.p. could be produced, but this died away almost immediately.

Tests were also carried out on the excitation failure contactors, and it was found that on failure of the auxiliary busbar voltage, the excitation supply was switched over to the standby battery with no more disturbance than a slight surging of the propulsion circuit ammeter.

The balanced voltage protection was tried in a similar manner by shutting down one main engine. When the speed of the latter had fallen by about 15 per cent. the corresponding generator balanced voltage relay operated, tripping the field contactor. The ship settled down to reduced speed on one generator with hardly any perceptible electrical disturbance.

1,000,000 kVA Metal Clad Switchgear.

A view of a 12-panel, 22kV metal clad switchboard in course of erection in the High Tension Works of the General Electric Co., Ltd., at Witton, Birmingham. Each unit is equipped with duplicate oil circuit breakers each of 1,000,000 kVA rupturing capacity and duplicate tubular type busbars. The board is to be installed in the Willesden Station of the London Power Co., Ltd. and will be coupled up to the lower tension side of the Grid.



The Manufacture and Testing of Accessories for Oil-filled Cables.

By R. E. HORLEY, A.M.I.E.E., A.M.A.I.E.E.

Works Manager, Eastleigh Factory, Pirelli-General Cable Works Ltd.

This is the second of a series of three articles dealing with oil-filled cables. It will be realised from the previous description that an oil-filled cable system depends entirely upon the correct functioning of all the accessories by means of which a constant oil pressure is maintained in each section of the cable.

It is the object of this article briefly to explain the various processes of manufacture, the numerous tests and the precautions taken to ensure the efficiency and reliability of each accessory.

As previously explained, an oil-filled cable installation is divided, hydrostatically, into a number of sections, in each of which is maintained a positive oil pressure under all working conditions of the cable.

In order to divide the sections hydrostatically and not electrically, it is necessary to install at each end of a cable section a stop joint which closes the central oil passage in such a way as to cut off oil communication between this section and the next, but at the same time to allow independent feeding of oil to either side of the stop joint if at any time this should be required. Space must be provided for the expansion of the oil when the cable heats up under load and, similarly, when the cable cools and contracts, oil must be returned to the cable. Provision is made for movement of the oil due to expansion and contraction by means of reservoirs of oil of calculated capacity connected to a section of the cable and situated at a height above it in order to obtain the necessary hydrostatic pressure, this being determined from calculations based upon the profile of the line.

These reservoirs are termed "feeding tanks." It is evident that the length of cable which may be fed from one source is limited and depends upon the viscosity of the oil and the resistance to flow offered by the central channel in the cable. The length of a section may be increased considerably, however, by the installation of a pressure tank which assists the feeding tank by taking in, or sending out, oil during the first part of a heating or cooling period of the cable. The action of this pressure tank, therefore, is to reduce the variation in pressure that occurs within the cable, thus allowing an increase in the length of working section. A section of an

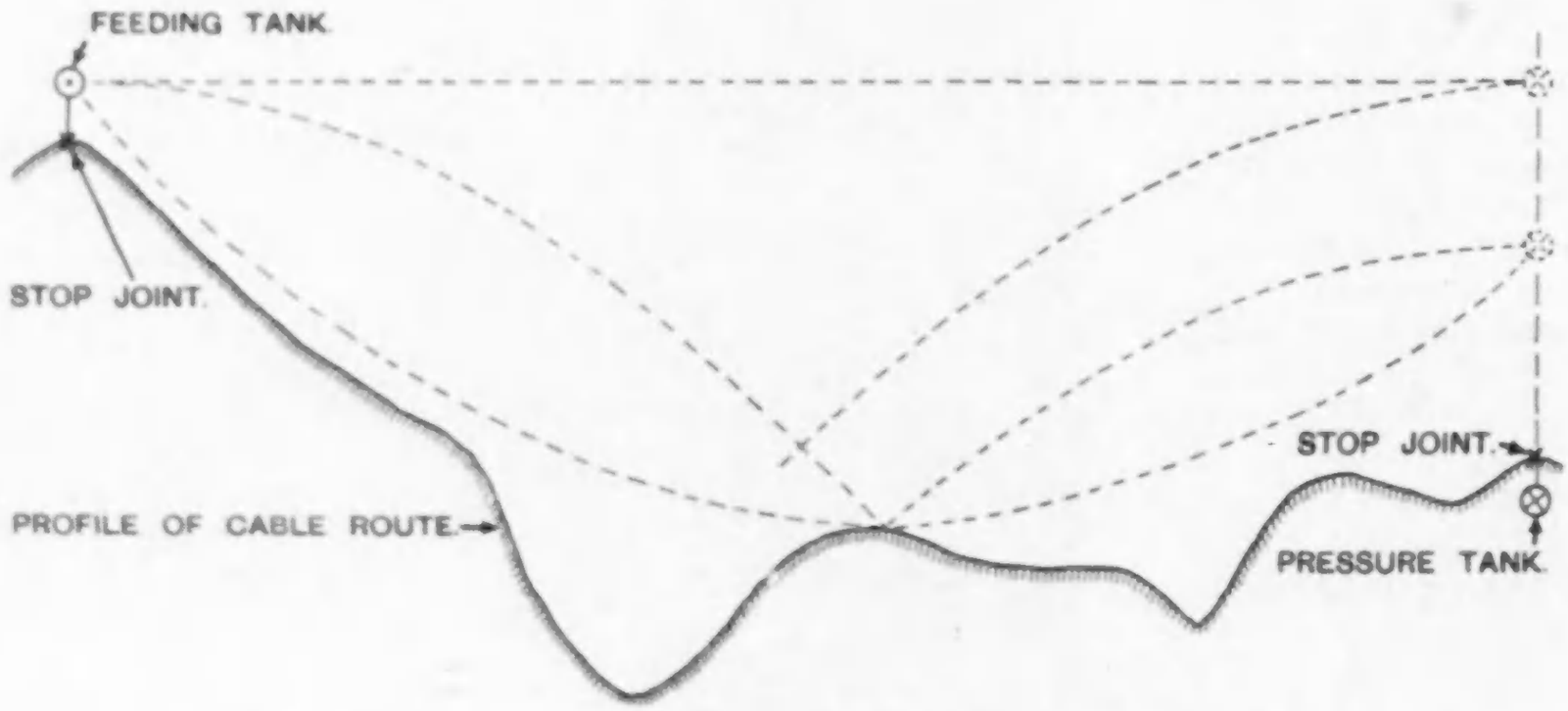


Fig. 1.—Diagrammatic section of an oil-filled cable installation showing positions of accessories.

oil-filled cable system illustrating the positions of the accessories is shown in fig. 1.

FEEDING TANKS.

In order that it may remain free from gas, it is essential that the oil in a feeding tank* shall not

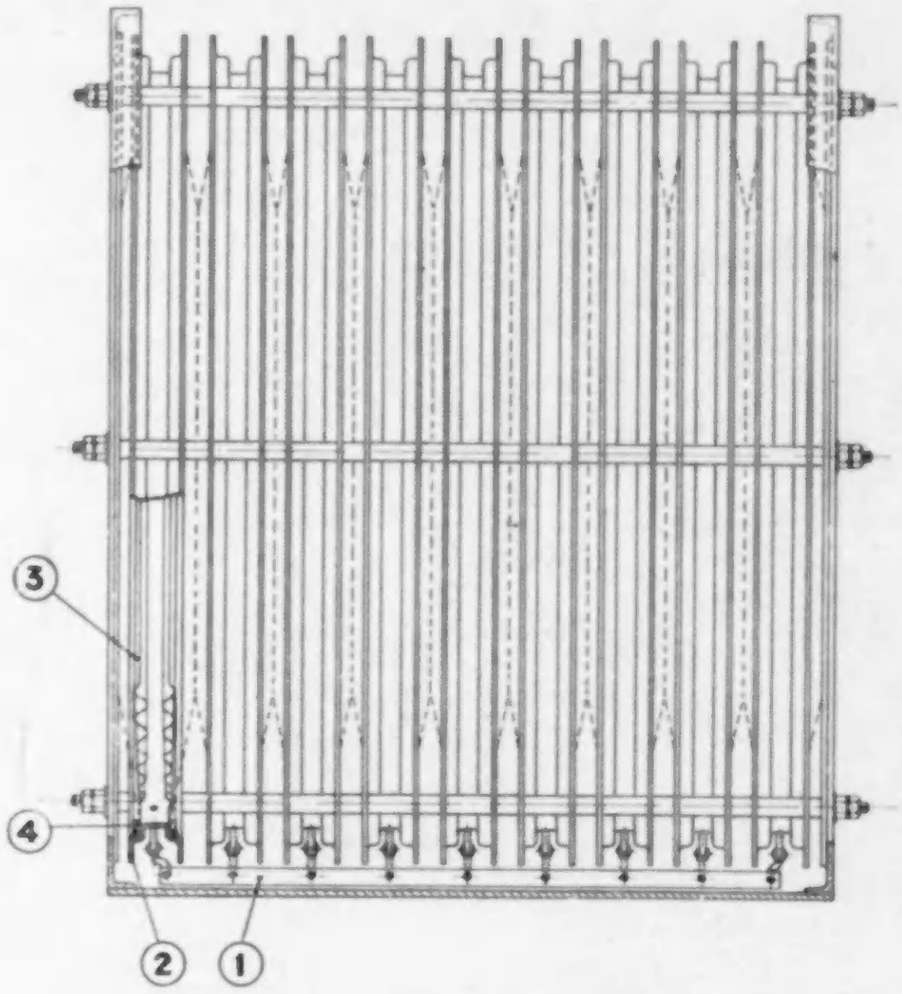


Fig 2.—Section of feeding tank.

come in contact with the surrounding air. It is also important that it be kept at practically atmospheric pressure, independent of the quantity of oil that is contained in the tank. These conditions have been fulfilled by constructing the reservoir in the form of a number of flexible walled cells made of corrugated nickel plates, the number and size of the cells depending upon the amount of oil required for the operating conditions in the cable at the particular feeding point.

Fig. 3.—Press in which diaphragms are tested.

A feeding tank is illustrated in fig. 2, having nine cells connected in parallel to a common manifold (1). Each cell consists of one tinned copper channel ring (2) at each side of which is soldered a corrugated monel metal diaphragm (3) with retaining ring (4). The corrugation allows the plates to move under changes of pressure. Two sizes of feeding cells or elements have been standardized, a certain number of these being paralleled together to form a tank, while a number of tanks may be paralleled together by means of valves and manifolds to give the necessary volume of oil. Monel metal, a natural copper-nickel alloy, is used for the cells because of its very high resistance to corrosion, coupled with its ability to withstand the fatigue caused by the expansion and contraction of the elements in service.

Fig. 4.—Soldering cells on special revolving tables.

In the manufacture of a cell, great care is exercised to ensure that there shall be no defects in the

* Pirelli Patent No. 267,059

component parts. The rings are carefully examined and the diaphragms, before being passed for use, are fixed in a special press (fig. 3) which, by means of a rubber packing ring, causes the diaphragm to close a chamber in an air-tight manner. Air is pumped into the chamber and the top of the diaphragm is flooded with oil. By this means any defects caused by the rolling of the sheet or in stamping the corrugation, are made visible.

Before soldering, all parts of the cell, including the rim of the diaphragm, are tinned in a hot bath of pure tin. The diaphragm and retaining ring are clamped on to the main channel ring on a special revolving table, seen in fig. 4. The parts are then heated by means of a gas blow pipe to approximately 250° C., and solder is flooded in at this temperature.

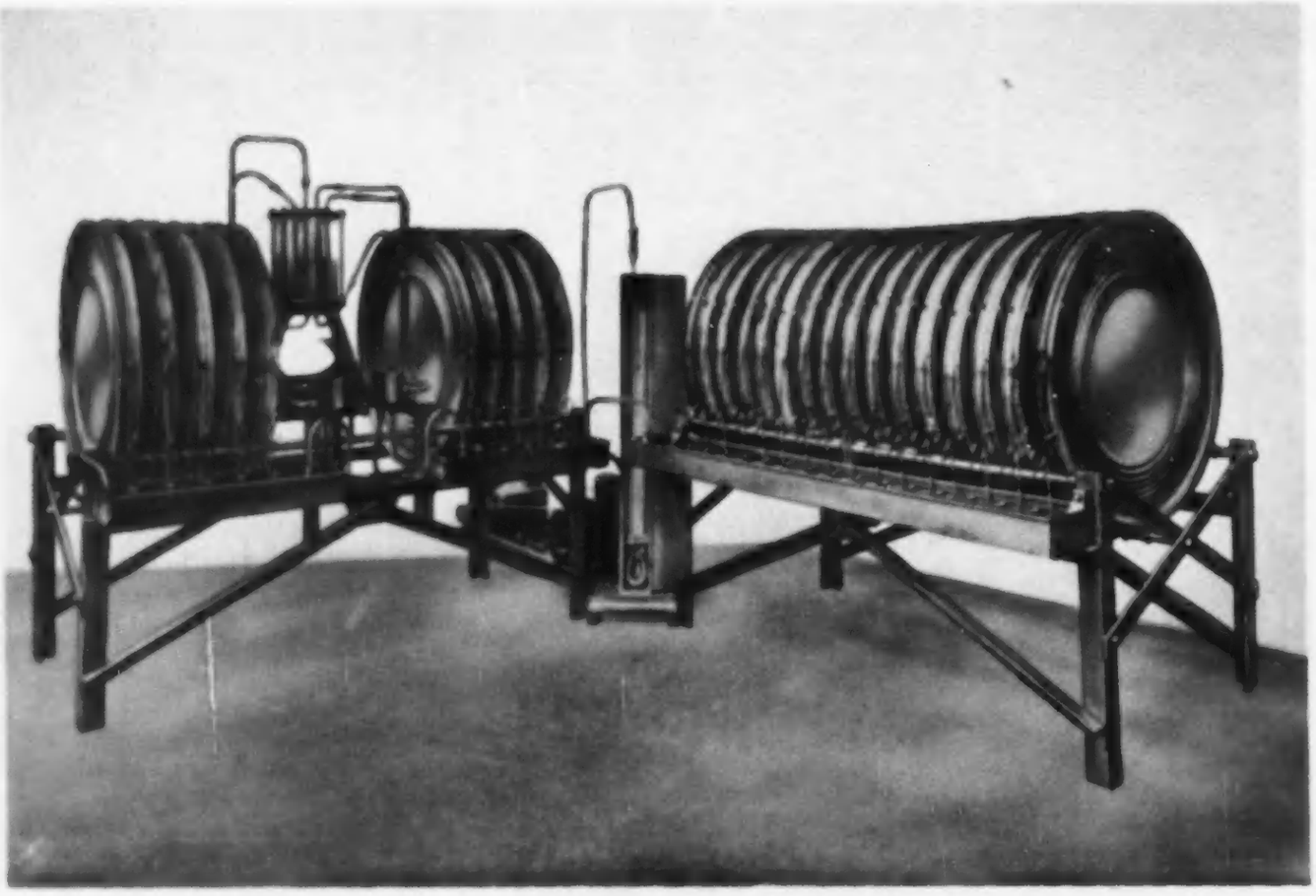


Fig. 5.—Testing feeding tank cells under vacuum.

TESTS.

Tests of the complete cell are carried out in the following manner.

(1) *Air Pressure Test.*

Compressed air is admitted to the cell until maximum working volume is reached. The cell is then placed in a special press, which, by compressing the cell, raises the pressure to 5 lbs. per sq. in., the cell being submerged in oil during this operation. Any considerable porosity in the soldered joint thus becomes immediately apparent. Experience has shown, however, that this test, although revealing faults of a decided character, is not a sufficient guarantee that the cell is capable of meeting the exacting conditions called for in service. An additional test is therefore necessary.

(2) *Vacuum Test.*

This test subjects the cell to a high degree of vacuum, obtained by means of efficient rotary pumps. The vacuum is checked by a mercury column corrected for barometer reading. The cell is then disconnected from the exhausting pumps by means of an oil immersed cock. After remaining in this condition for twenty-four hours, the barometer reading is taken and the degree of vacuum observed. For the cell to be passed as

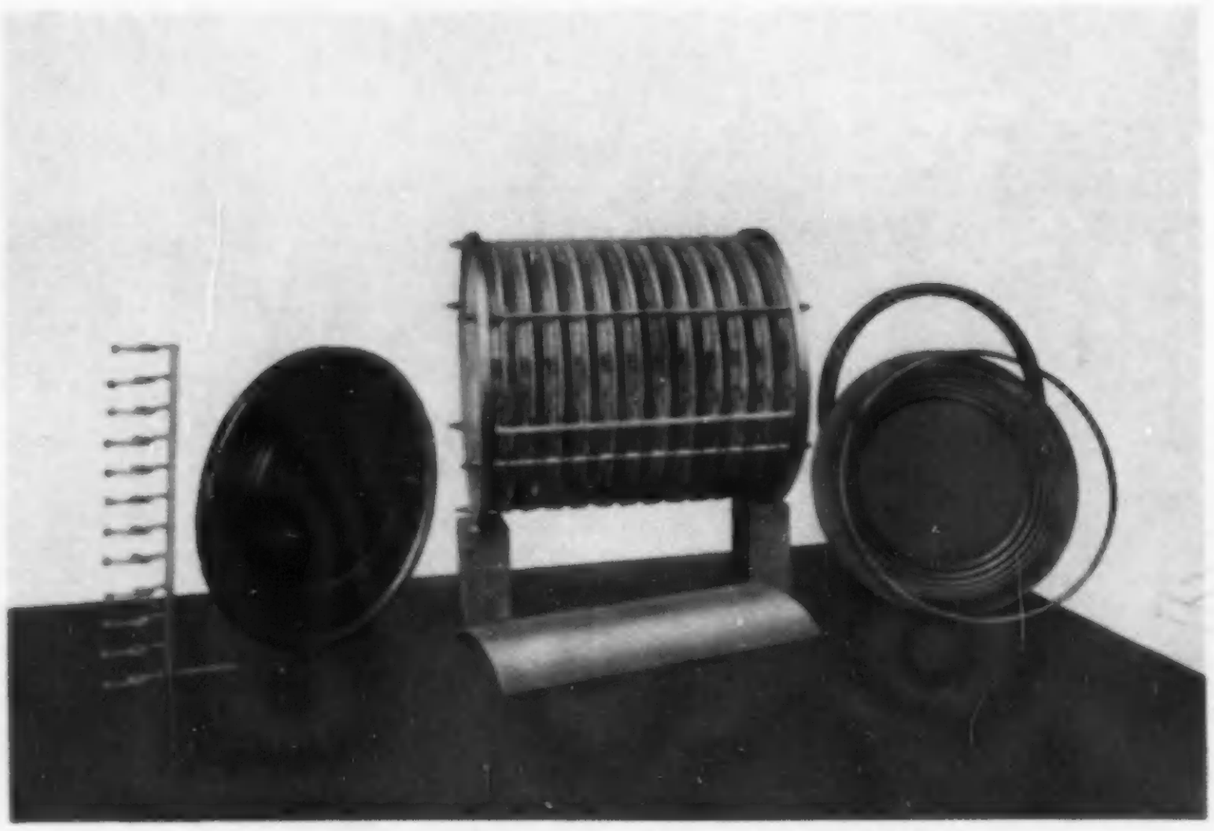


Fig. 6.—Assembly of feeding tank.

satisfactory, there must be no visible change in this reading. A view of the cells undergoing test by vacuum is illustrated in fig. 5.

THE LIFE TEST.

From every batch of monel metal diaphragms, two sample cells are made up and are tested on a machine which, in a few days, subjects them to the stresses experienced over a number of years of normal working. The two cells are connected through a valve to a small circulating pump. When one cell is filled with oil, vacuum is obtained in the other. The function of the pump is to fill and empty the cells from one to the other, a special trip mechanism, which operates automatically through a four-way valve, changing the suction side to the delivery side. This operation is allowed to continue day and night and a counter, fixed to one of the cells, indicates when the 10,000 cycles necessary for this test are completed.

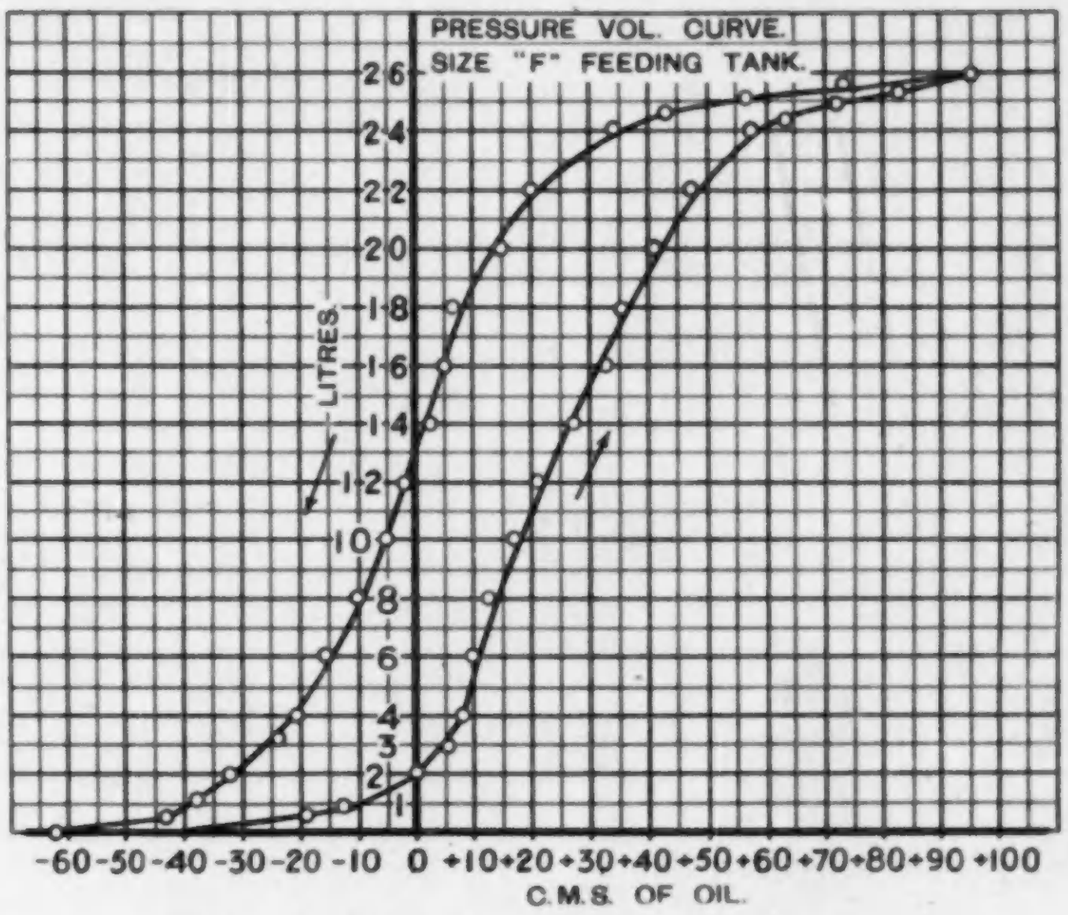


Fig. 7.—Typical pressure-volume curve.

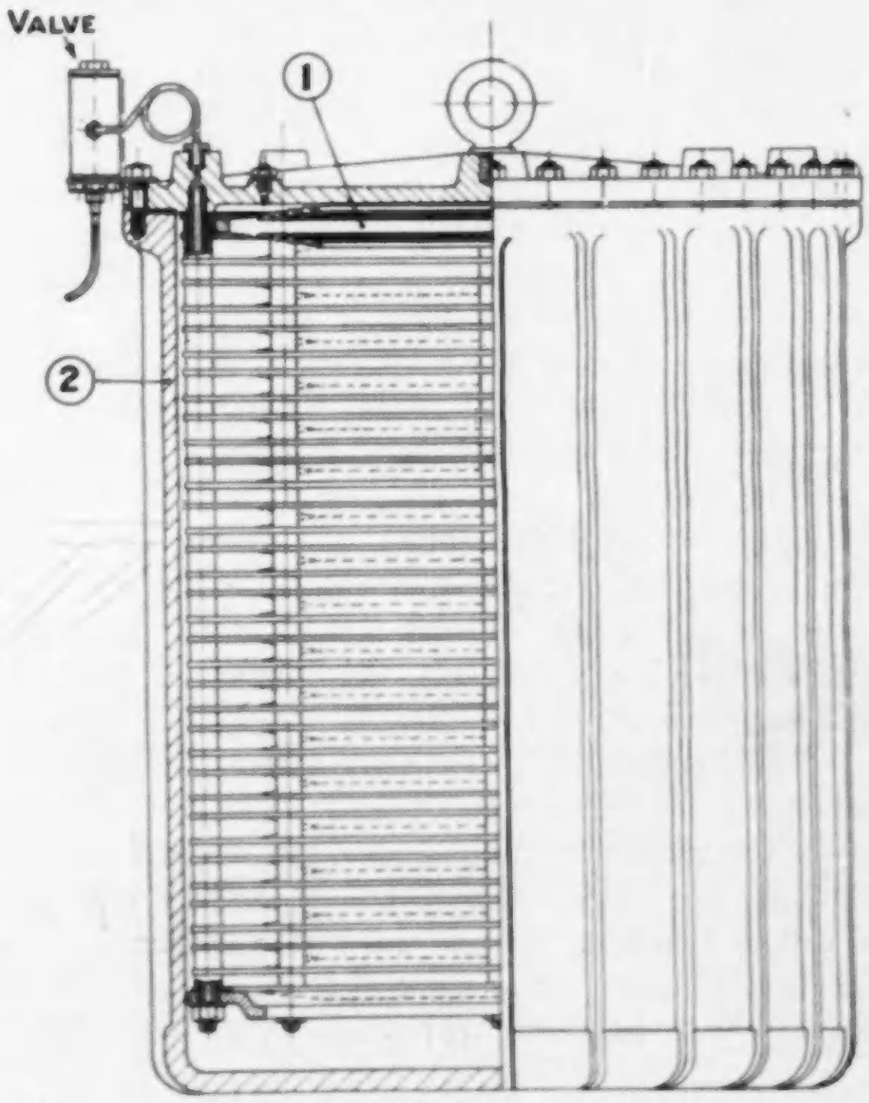


Fig. 8.—Section of pressure tank.

ASSEMBLY OF FEEDING TANK.

The cells, after passing the above tests satisfactorily, are connected together in their required numbers by means of steel bolts which pass through holes drilled in the copper ring of the cell. To permit of maximum expansion the necessary distance between each cell is maintained by means of steel distance pieces, as shown in fig. 2.

The expansion of the two outer cells is limited by steel discs which also afford the necessary mechanical protection. The discs carry two angle iron rings on which the tank can be rolled.

The manifold, which may be seen on the left hand side of fig. 6 connects the cells in parallel, and is built up from an extruded brass section. Copper pipe connections are brazed in position, the connection between the manifold and each cell being of the conical union type.

The manifold, before assembly, is subjected to air and pressure tests similar to Nos. 1 and 2 described in the test section, and is protected from injury by a steel plate cover seen in the foreground of fig. 6.

TEST OF COMPLETED TANK.

(1). A vacuum test is applied to the completed tank in the manner described in Test No. 2 for the single cell, the same figures of vacuum being obtained and maintained.

(2). The tank is filled to its maximum capacity with hot, dried, degasified oil and allowed to stand in this condition for three days. At the end of this period it is again carefully examined.

(3). Before despatch, a sample of the oil is taken and is tested between a standard gap at a voltage of 50 kV, a pressure which it must withstand without breakdown for thirty seconds.

A typical pressure-volume curve is illustrated in fig. 7, from which it will be observed that the hysteresis is very slight.

PRESSURE TANKS.

In principle, a pressure tank differs from a feeding tank in that the former does not depend upon gravity for its action, and need not be placed at a height above the cable.

As illustrated in fig. 8, a pressure tank consists of a certain number of collapsible gastight cells (1) filled with gas under pressure and contained in the tank (2), which is filled up with oil. It will be seen from fig. 1 that if the pressure tank is connected to the cable at a distance from the feeding tank, the oil in the pressure tank and the gas inside the cells are subjected to the pressure corresponding to the static head of oil from the feeding tank. When the cable cools down at a point distant from the feeding tank, but near the pressure tank, the pressure within the cable falls and the gas enclosed in the collapsible cells of the pressure tank increases in volume and pushes out the oil from the tank into the cable. When the cable has cooled and steady conditions prevail, the feeding tank sends oil into the pressure tank and restores it to its static pressure. As soon as load is switched on, the temperature of the cable rises and the oil expands. At a point in the cable remote from the feeding and pressure tanks the pressure in the oil rises. Oil is sent in both directions and causes the pressure in the pressure tank to increase.

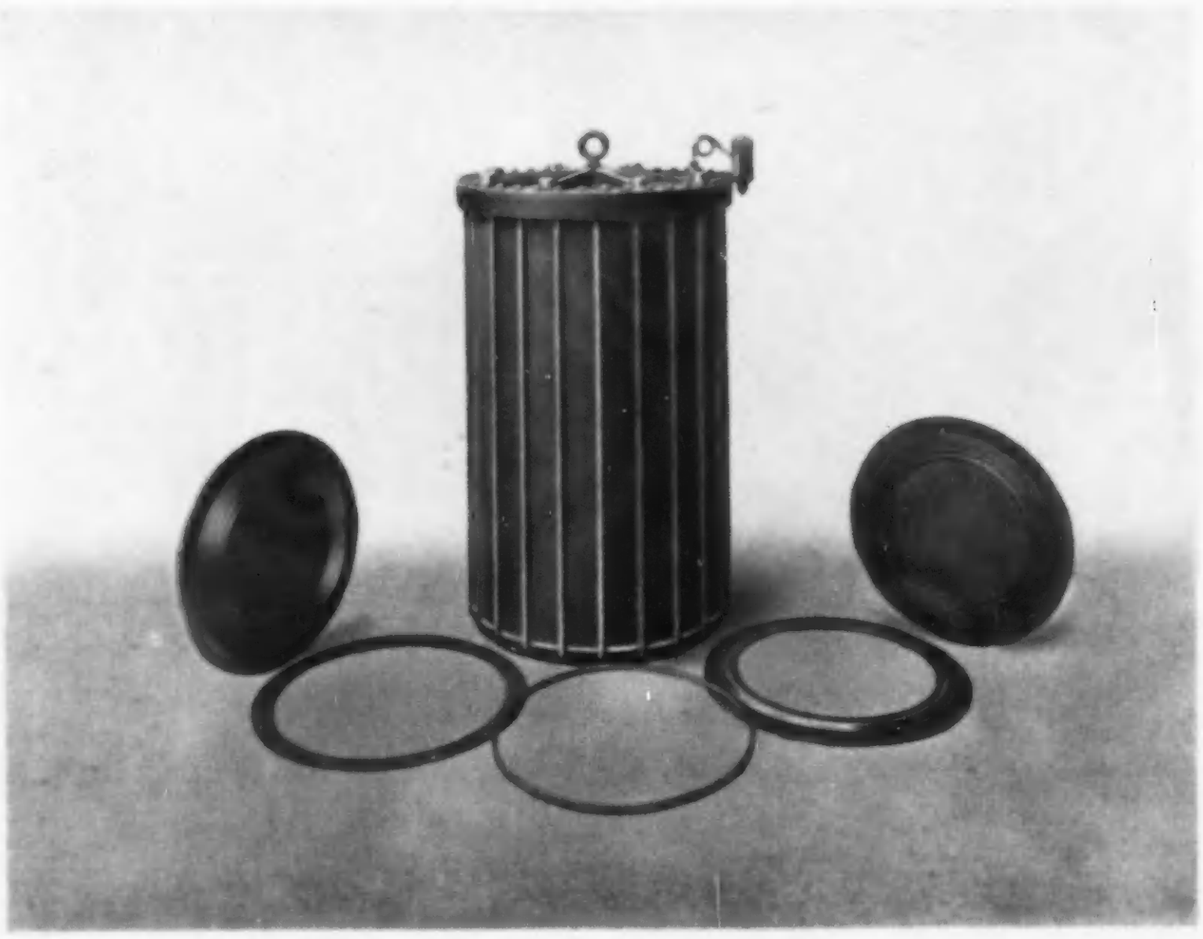


Fig. 9.—Assembly of pressure tank.

After the cable has reached its maximum temperature for the particular load and conditions remain constant, the pressure tank sends oil into the feeding tank and its pressure falls to the initial static value. The function of the pressure tank, therefore, is to reduce the pressure variations that occur within the cable, and thus to allow an increase in length of working section.

The pressure tank, shell and cover are high grade iron castings, ribbed as shown in fig. 9, the cover being secured by a number of high tensile steel studs. The faces between the cover and shell are machined to ensure a perfectly oil-tight joint.

Each cell consists of two corrugated German silver diaphragms soldered together and strengthened by the inclusion of a solid steel ring which may be seen in the foreground of fig. 9. The cells are clamped together by cast iron rings (seen on the left and right of the solid steel ring) which are retained by studs screwed into the cover, the distance pieces being provided to maintain the required distance between the cells. By this arrangement not

only may all the cells be removed for inspection by merely lifting the cover, but ease in assembly is also secured. As it is preferable to drain the oil from the bottom of the tank, one of the studs is made hollow, so constituting an oil pipe which is connected through the cover to a copper pipe, connected to a valve, as seen in fig. 8.

The shell and cover are tested with paraffin at the foundry to 70 lbs. per sq. in. and are left under this pressure for forty-eight hours. They are then closely examined for porosity. This test is very searching, and it was only after considerable experimenting that castings could be made which would pass it satisfactorily.

Apart from the quality of the iron, trouble was experienced in centralising the core owing to the fact that the usual foundry methods were found to be unsuitable, leakage invariably occurring where

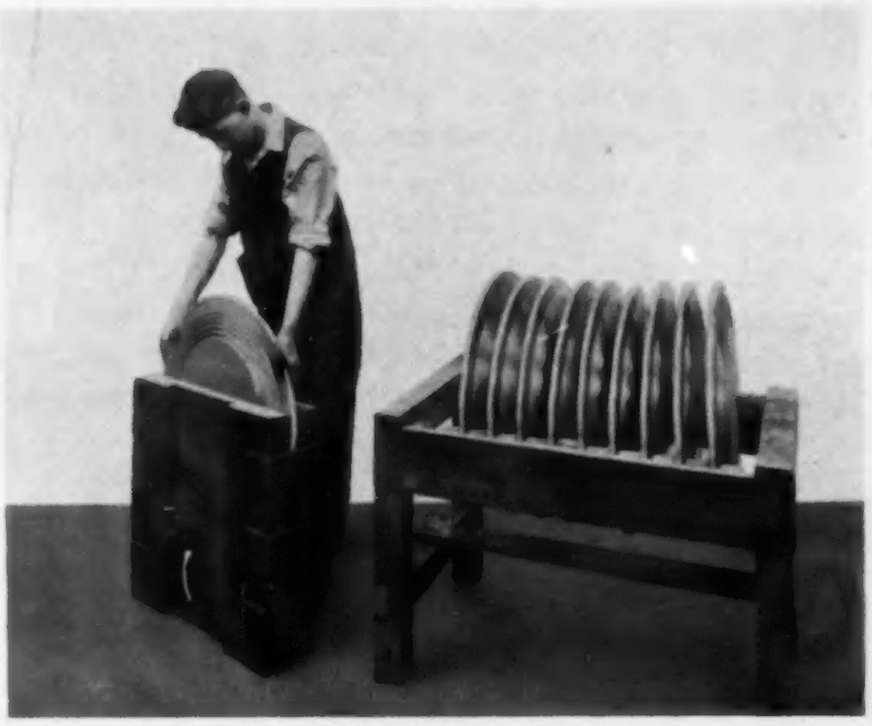


Fig. 10.—Gauge for checking volume of pressure tank cell.

chaplets had been used. This was overcome by increasing the height of the tank, placing the chaplets at the top and machining off the top of the tank and the chaplets. The castings are thoroughly cleaned, and coated internally with a synthetic resin varnish, a preparation insoluble in oil. This varnish prevents any minute particles of sand which may be engrained in the metal, becoming dislodged and contaminating the oil.

Unlike those of the feeding tank cells, the diaphragms of the pressure tank cells are joined by one soldered joint, one diaphragm overlapping the other, the solder being applied by an iron in the usual manner. A small aperture is left which is finally sealed after the cell has cooled down to a predetermined temperature. By this means approximately constant volume is obtained. Before sealing, the volume is checked by means of a gauge (fig. 10), any corrections being effected by means of compressed air. The completed cell is tested by compression under oil in a similar manner to that described for the feeding tank. A number of cells are then placed in a tank, which is filled with cable oil to a pressure of four atmospheres and left for forty-eight hours, after which the cells are removed and examined for leakages.

The assembly of a pressure tank is a comparatively simple operation and will be readily

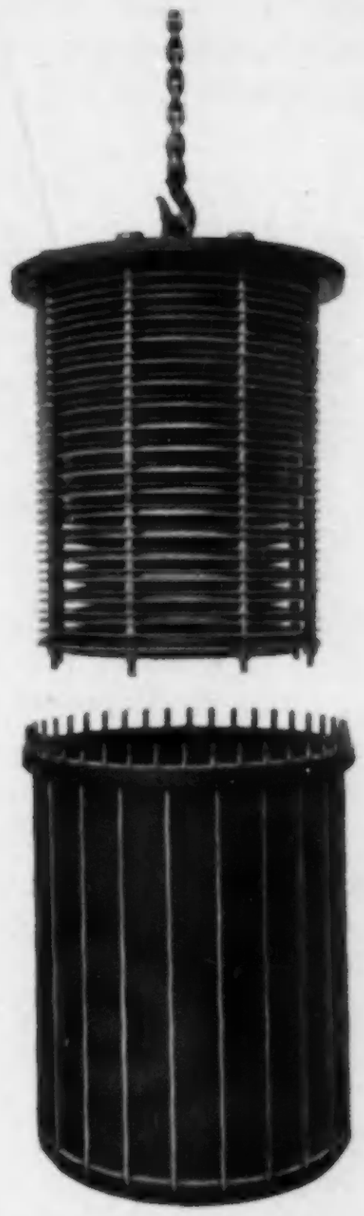


Fig. 11.—Lowering assembled pressure tank cells into tank.

understood from the earlier part of the description and by reference to fig. 11. The joint between cover and shell is made with a special jointing paper previously impregnated with gold size.

The complete tank is then filled with dried degasified oil by a submerged gear-type pump which is connected to a degasifier. The oil is pumped into the tank through the valve (fig. 8), a blank union, situated in the cover being removed to allow the egress of air.

Oil is circulated through the tank until the air has been removed; the blank connection is then replaced and the pumping continued until the required pressure of four atmospheres is obtained. The following tests are then made.

(1). The tank is allowed to remain at this pressure for forty-eight hours and it is then carefully examined for oil leaks, special care being taken to ascertain that the joint is sound.

(2). The average capacity of each cell is checked by drawing off a certain quantity of oil to reduce the pressure to a suitable figure. The tank is then connected to a mercury manometer, the reading of which is carefully noted. Five gallons of oil are drawn off from the tank, and the reading is again taken, from which the average volume may be obtained from a simple formula.

After these tests, pressure is adjusted to that required for despatch (*i.e.*, 5 lbs. per sq. in.,) and, finally, the tank is painted.

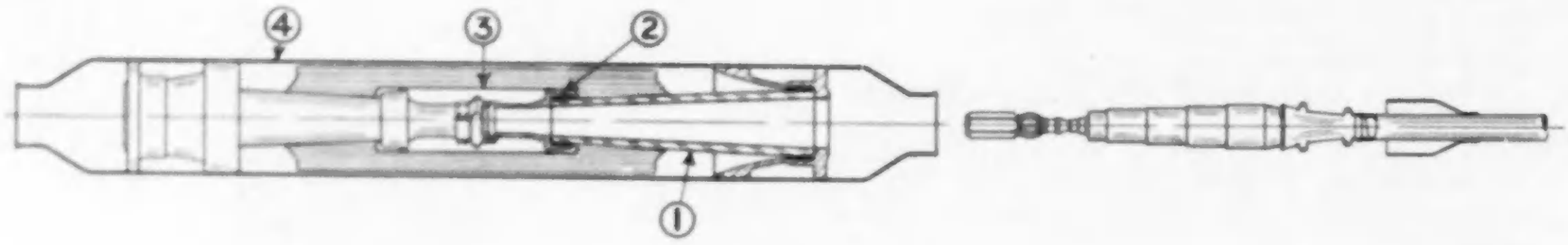


Fig. 12.—Section of stop joint.

STOP JOINTS.

As explained at the beginning of this article, stop joints are used to connect two sections of the cable electrically and to stop any oil communication between them*. At the same time, it must allow the feeding of oil to either side. A drawing of a complete stop joint is given in fig. 12. That part of the assembly and insulation of the joint which is carried out in the factory, is effected in the following manner.

All parts having been carefully machined and prepared, the two porcelain insulators (1) are cemented into their metal fittings. Between the faces of the porcelain and metal fittings, at each end, special packing rings are used to ensure an oil-tight joint.

During the cementing operation, the whole is effectively clamped longitudinally to ensure that the packing is highly compressed against the faces, the joints being carefully tested under vacuum before being passed for use. The two terminals (2) are now ready for connecting together and are aligned on a special bench as shown in fig. 13. The couplings between the terminals are then fitted.

The next stage is the fitting of the electrostatic control (3) which consists of a highly polished copper spinning, split longitudinally and secured by a soldered joint, all corners and edges being carefully rounded off. The shield is bonded to the joint terminal by an internal flexible copper strand. The joint is then ready for insulating.

The insulation next to the electrostatic control is formed by paper strips bound with a fine silk thread until the required thickness is obtained. The radius formed by the electrostatic control is filled in with a specially folded paper tape, as it

* Pirelli Patent No. 268,271.

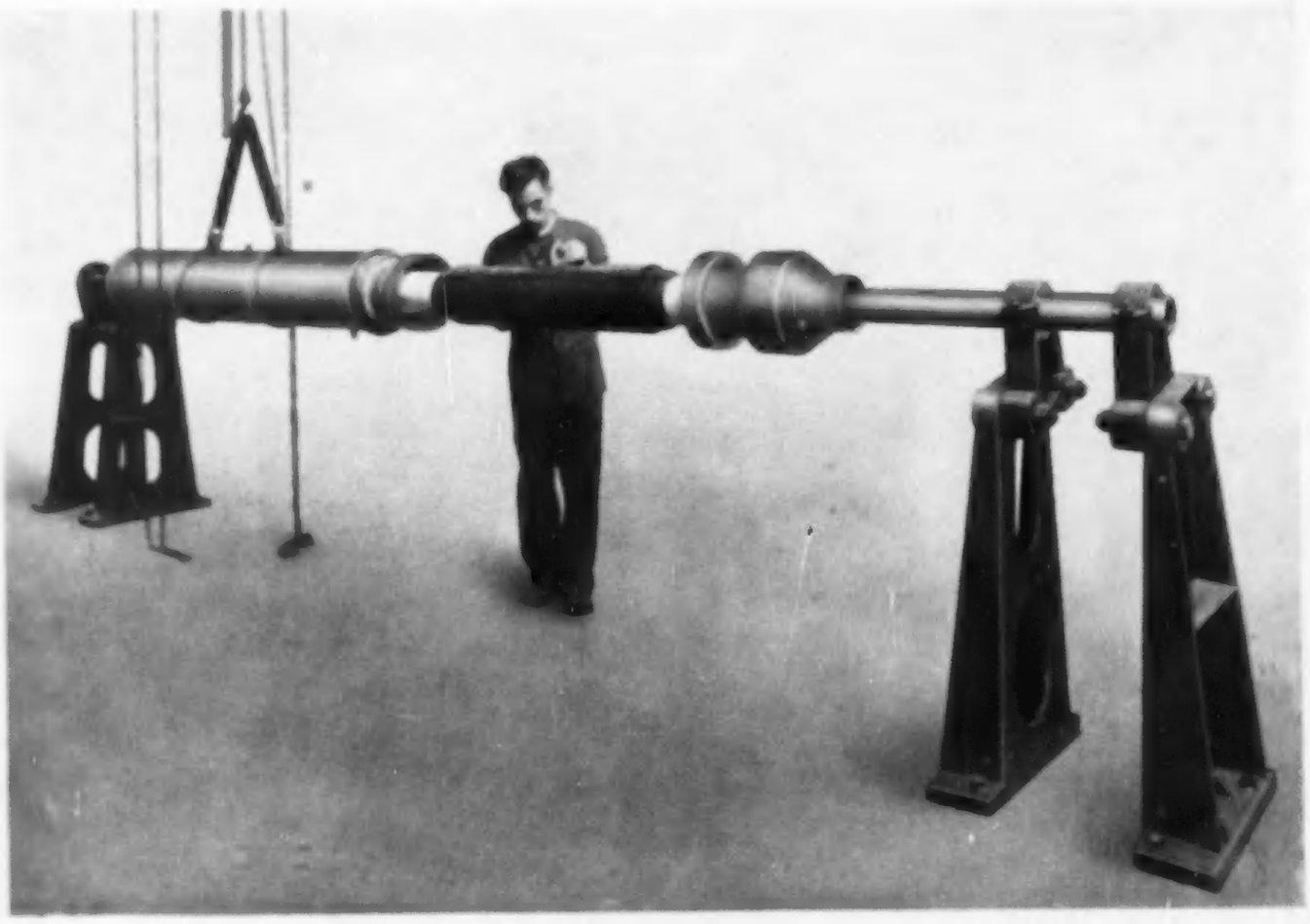


Fig. 13.—A stop joint assembly bench.

will be appreciated that it would be impossible to carry the longitudinal paper tape over this contour without leaving undesirable spaces.

The final insulation is made by a paper roll which is wound tightly around the joint.

The main copper sleeve (4), fig. 12, is now slid into position and is retained by a number of grub screws, which are wiped over with plumbing metal, the joint between the sleeve and the cast gunmetal ends being made in a similar manner.

due to handling, the cable length would not remain completely filled with oil unless precautions are taken to counteract this tendency. The necessary compensation is effected by incorporating in the drum a tank filled with oil under pressure, and connected to the cable length.*

The drum pressure tank, fig. 14, consists of a length of solid drawn steel tubing (2) closed at the ends by metal plates which are screwed and sweated into position to maintain oil-tightness.

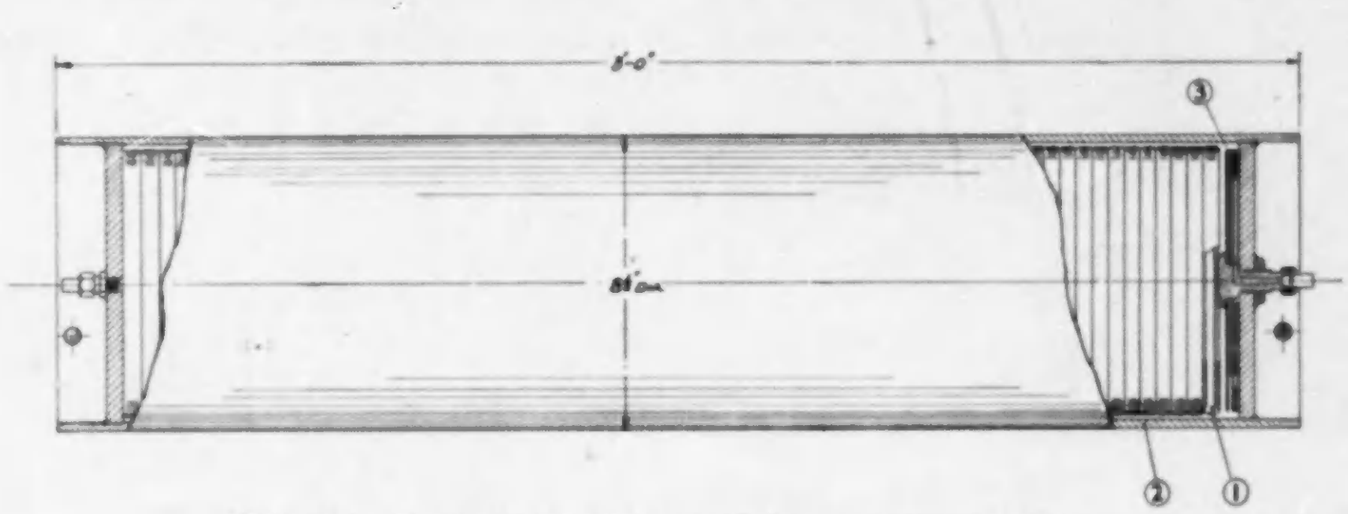


Fig. 14.—Part sectional view of drum pressure tank.

IMPREGNATION AND TEST.

Before impregnation, the joint is heated by means of a steam coil wound round the sleeve and subjected to vacuum for several hours. Impregnation is effected in exactly the same way as that described for the cable itself and when completed, an impregnation test is also made on the joint. The joint is then electrically tested to the same specification as the cable itself, after which it is ready for despatch.

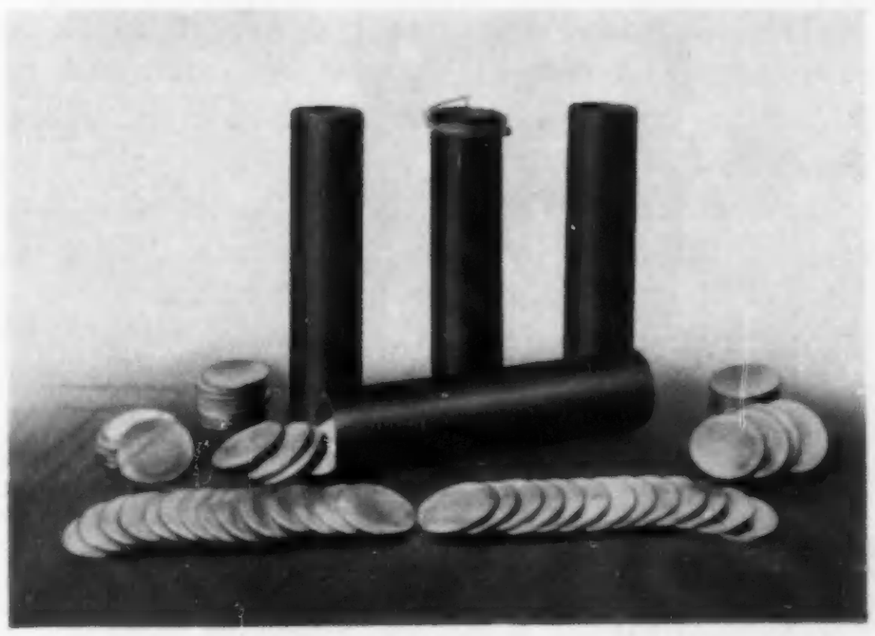


Fig. 15.—Components of drum tank.

DRUM TANK.

Although every length of oil-filled cable is despatched from the factory completely filled with oil, it is evident that, owing to temperature differences between factory and site, to bending of the cable, or to slight deformation of the lead sheathing

The cells (1), fig. 14, are similar in design to those used on the normal pressure tank, but are of much smaller dimensions, fifty of them being required for every drum tank. The amount of oil given out by the tank between one and fifteen pounds pressure per sq. in. is approximately three gallons, and this is sufficient for about a quarter of a mile of cable through winter and summer.

Although similar in design to the normal pressure tank cell, the drum tank is made of tinned steel sheets, the use of cheaper metal being consistent with the fact that they are employed as a temporary measure only. The cells are soldered together in a similar manner to the normal type pressure tank cells and are also tested in the same manner. The inner surfaces are cleaned by sand blasting and painted with a synthetic resin varnish. Drum tanks with cells arranged at the sides are shown in fig. 15.

The tanks before despatch are tested and filled with dried and degasified oil, as with the pressure tanks already described, the pressure of oil when despatched being that required for the particular type of cable with which it is to be used.

END SEALING TERMINALS.

The oil-filled cable is connected to end sealing terminals of the type shown in fig. 16. The ferrule which connects the cable to the top of the terminal acts as a valve so that, upon withdrawal of a steel pin, oil can be fed into the cable. The insulation of the cable at the end of the lead sheath is reinforced by means of a paper roll (2) and fitted with a metal electrostatic control (3). The prepared end is

* Pirelli Patent No. 304,912

inserted into the end sealing terminal, and the ferrule soldered in position at the top (4). The inner lead of the cable is plumbed to the bottom section of the base casting (5). The end sealing terminal is impregnated under vacuum, after which the valve connecting the interior of the cable with the sealing terminal is opened, thus allowing the oil to be fed from the feeding tank through the sealing terminal into the cable. Finally, the end sealing terminal is fitted at the top with a covering shield. In fig. 17 are shown end sealing terminals in different stages of construction.

End sealing terminals for 66 kV and higher voltages are built up in the following manner.

The shedded porcelain insulator is cemented into a gunmetal ring and is secured to the main casting by a number of steel studs, a special oil proof packing compressed between the faces forming an oil-tight joint. The arcing rings are also secured by these studs.

Fig. 17.—End sealing terminals in different stages of construction.

The electrostatic control (3), fig. 16 is made from machined and highly polished gunmetal or aluminium castings, and is clamped around the paper roll (2), fig. 16.

The connection between the cable and the terminal is made by a copper ferrule which is clamped to the conductor by a hydraulic press. This ferrule incorporates the valve which isolates the terminal from the central channel and enables a vacuum to be obtained on the sealing end before impregnating. After impregnation, the valve spindle is removed and the oil in the terminal is then in contact with the oil in the cable. The terminal connection is a gunmetal casting fitted with a copper stud and the whole is protected by an aluminium cover.

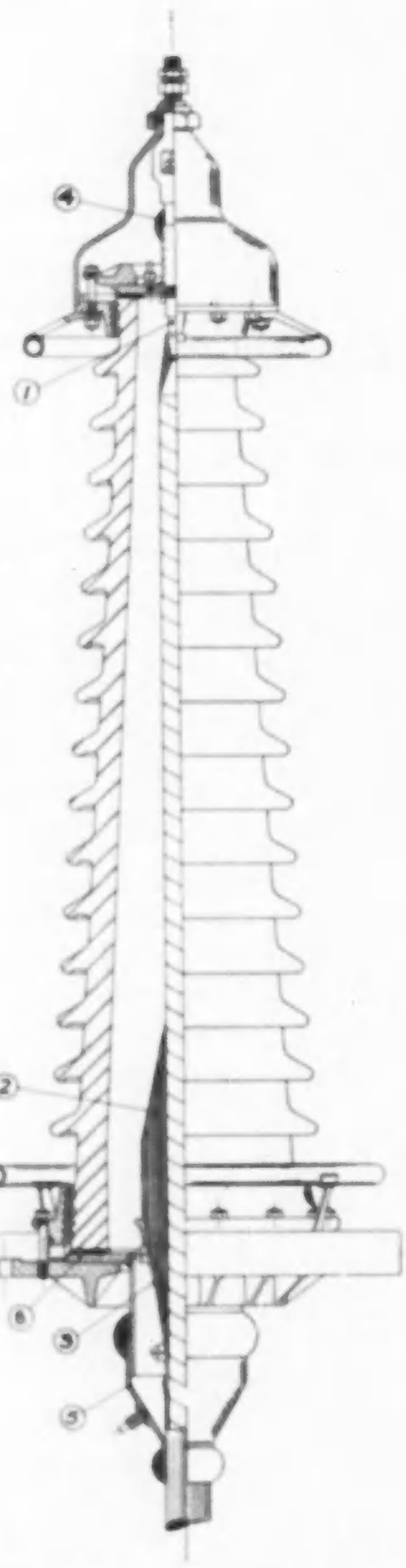


Fig. 16.—End sealing terminal.

Industrial Electric Heating.

PART 1.

General Considerations and Inherent Characteristics.

By VERDON O. CUTTS.
Industrial Heating Dept. of The General Electric Co., Ltd.

In this, the first article of a series dealing with the use of resistance type furnaces for industrial electric heating, the author outlines the economic and material advantages to be gained by the use of electrically produced heat.

Subsequent articles will be devoted to discussions on various practical applications and will include the important subject of heat treatment of metals.

THERE are few articles of commerce which are not subjected to heat at some stage of their manufacture, and since the application of electrically produced heat to innumerable industrial processes is daily receiving consideration in almost every trade, the subject has become one of considerable importance. Indeed, the number of industries in which electric heating finds employment on a commercial scale is already very extensive. This is the outcome of that demand for precision and efficiency which the present tendency towards improved manufacturing methods and equipment has created. It is already recognised that, with electric heating, a degree of exactitude hitherto regarded as commercially impracticable is now attainable on a production basis under ordinary shop conditions.

ECONOMIC CONSIDERATIONS.

It is impossible to appraise the value of any improvement in industrial technique without taking into account economic considerations. Unless a process or application is capable of being justified by the ultimate cost in relation to the value of its product it cannot be defended. Experience suggests, however, that it is necessary to stress the fact that economic considerations in relation to industrial heating involve a great deal more than a comparison of the cost per unit of heat, *i.e.*, a comparison of the b.t.u. cost of electricity and fuels may be definitely misleading. The efficiency with which the heat is applied to the charge is an equally important factor. One thousand heat units, bought in a form which permits of seven hundred units being usefully employed, are capable of competing with the same number of heat units bought at a quarter the cost, but in a form which allows only 150 units to be made available for useful work. It is therefore necessary to take into consideration the inherent characteristics of each available fuel or source of heat in order to obtain a true estimate of their comparative values. When this is done it is frequently established that electric heat can be applied to industrial processes on an economic basis even in cases where its cost on a b.t.u. basis may not, at first, appear to be competitive. It is thus necessary to enumerate and consider the characteristics of electrically produced heat as applied to industrial processes.

CONTROL OF HEAT.

Electric heat is capable of being controlled to an exceptional degree and with great ease in all the following respects :

1. Positionally and directionally.
2. Quantitively and qualitively.
3. As regards atmosphere.

The facility with which electrically generated heat can be applied just where it is wanted is obvious. The heat is generated in elements which can be fixed in any position in relation to the charge. It may be strictly localised or widely diffused. It can be applied to the charge from above, below, or from all sides.

Any desired quantity of heat may be generated electrically at any desired temperature. There is a sufficient variety of resistance materials available to cover a wide range of temperatures. It is therefore apparent that, while steep temperature gradients are readily obtainable electrically, it is also possible to work with shallow temperature gradients in an open furnace without sacrificing uniformity of heat distribution. It is a well-known fact that

fuel-fired furnaces usually work with a steep temperature gradient, necessitating recourse to a variety of means to mitigate the effect; also that slight temperature gradients are usually obtained in fuel-fired furnaces at the expense of uniform heat distribution.

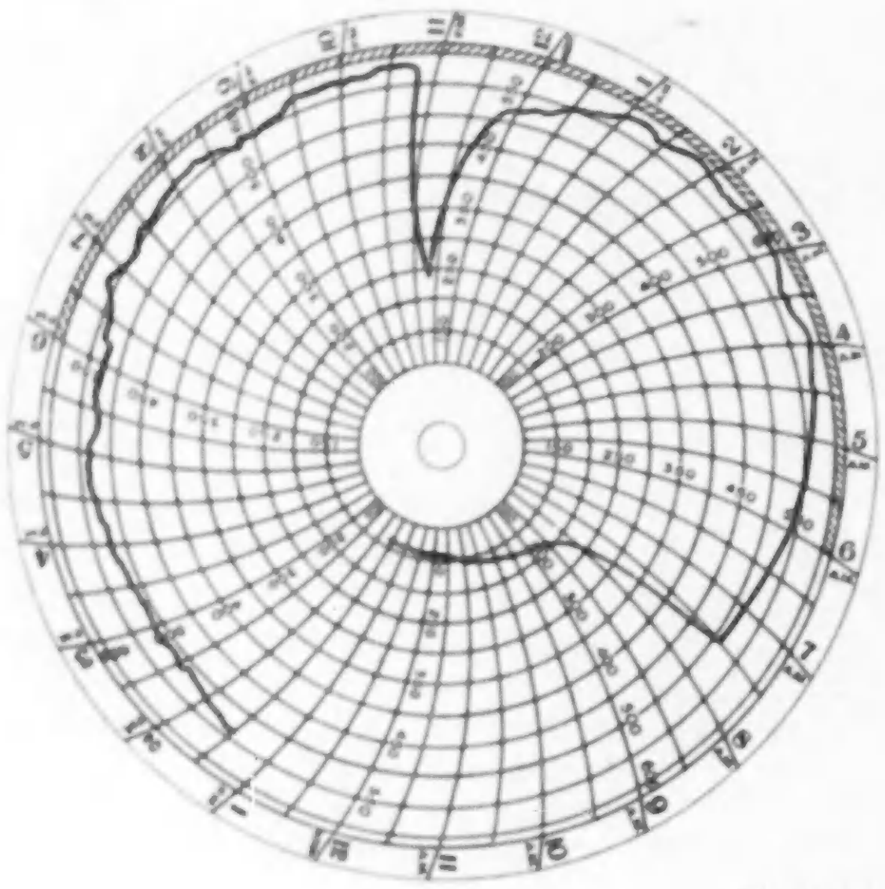


Fig. 1.

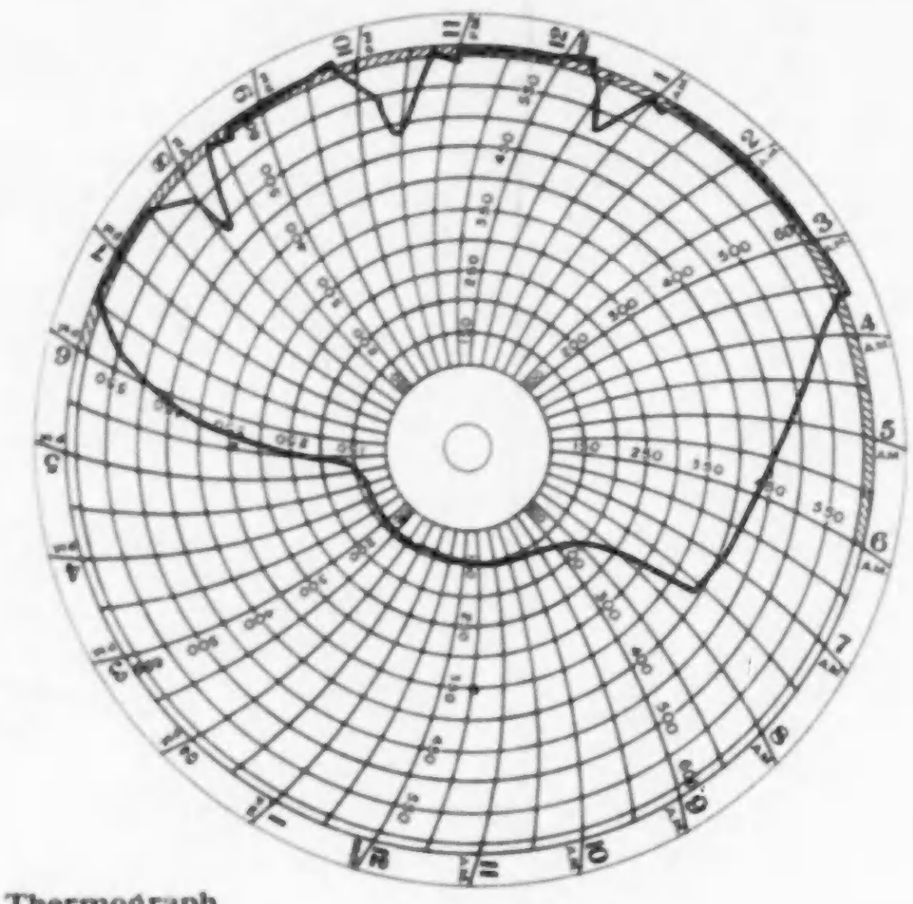


Fig. 2.

Fig. 1 to 4.—Thermograph records of a fuel-fired furnace.

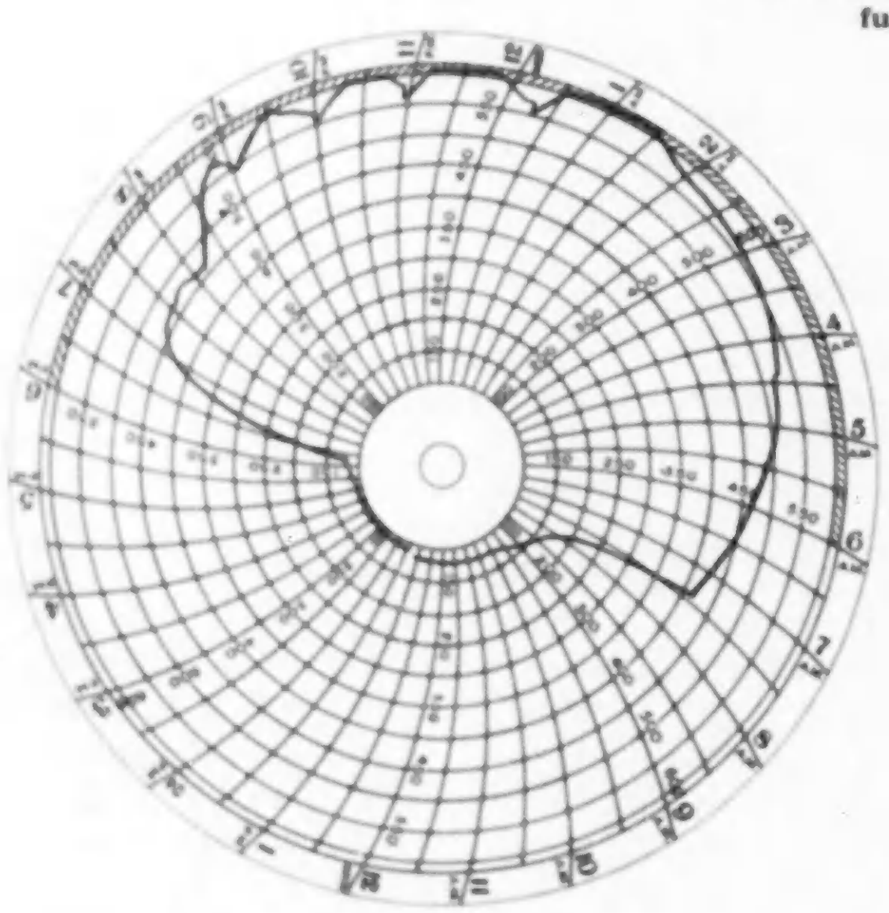


Fig. 3.

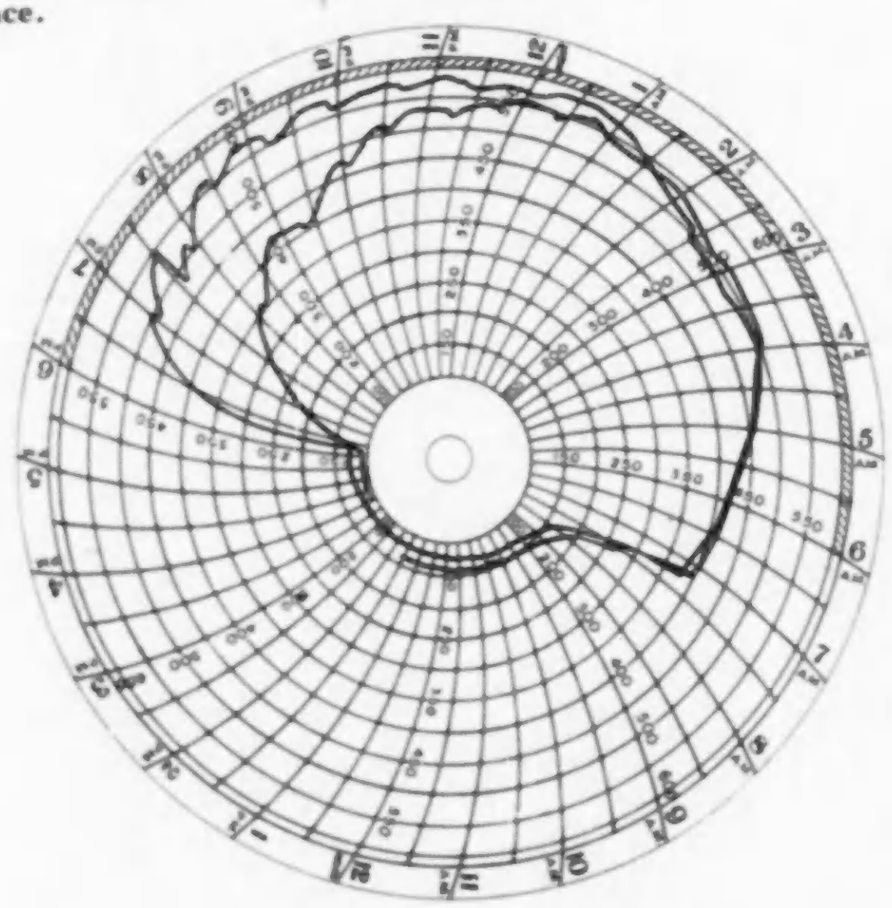


Fig. 4.

There is a definite relationship between the electrical input and the heat input to an electric furnace. This relationship is independent of such secondary considerations as the admission of air in the correct proportion for combustion purposes.

These features largely contribute to the ease with which electrically produced heat may be subjected to automatic control. Pyrometric and thermostatic control of an electric furnace are positive, dependable and precise. Any desired temperature can be obtained and held without appreciable variation and for practically any desired time. Previous heat-treatment programmes which have proved successful can be repeated with precision, and the ease with which this is accomplished under ordinary shop conditions and without skilled labour is of considerable importance and has, in many instances, revolutionised works practice.

The thermograph records shown in figs. 1 to 4 illustrate the normal results obtained in a fuel-

fired furnace in a large engineering works. The deep depressions in the curves correspond with the firing or stoking times. Fig. 4 is especially interesting as an illustration of the work carried out on two successive nights. Owing to the importance of the work in hand, the chart was left on the recording instrument and the most skilled operator available was entrusted with the task of repeating the heating programme of the previous night with an exactly similar load. The assiduity with which he did his work is shown by the shallowness of the depressions corresponding with firing periods. The shop foreman produced this graph with pride because he regarded it as an exceptionally able performance on the part of the attendant. The variations from the 550 degrees aimed at are obvious.

A pyrometer record showing how the temperature of a large electric furnace was maintained automatically and without any manual attention whatsoever is reproduced in fig. 5. In this instance the actual deviation did not exceed plus or minus three degrees.

With electrically heated equipment, it is possible under ordinary works operating conditions to ensure an exceptionally uniform temperature throughout the whole furnace and charge. This is illustrated by the accompanying table. The furnace from which these temperature readings were taken is 19 ft. long and 12 ft. wide, with an internal capacity of approximately 1,000 cu. ft. A sectional view of the furnace is illustrated in fig. 6. Carefully checked and calibrated pyrometers were used to record simultaneously the temperatures in four parts of the furnace. The readings given in column A were from a thermo-couple 10 ft. long

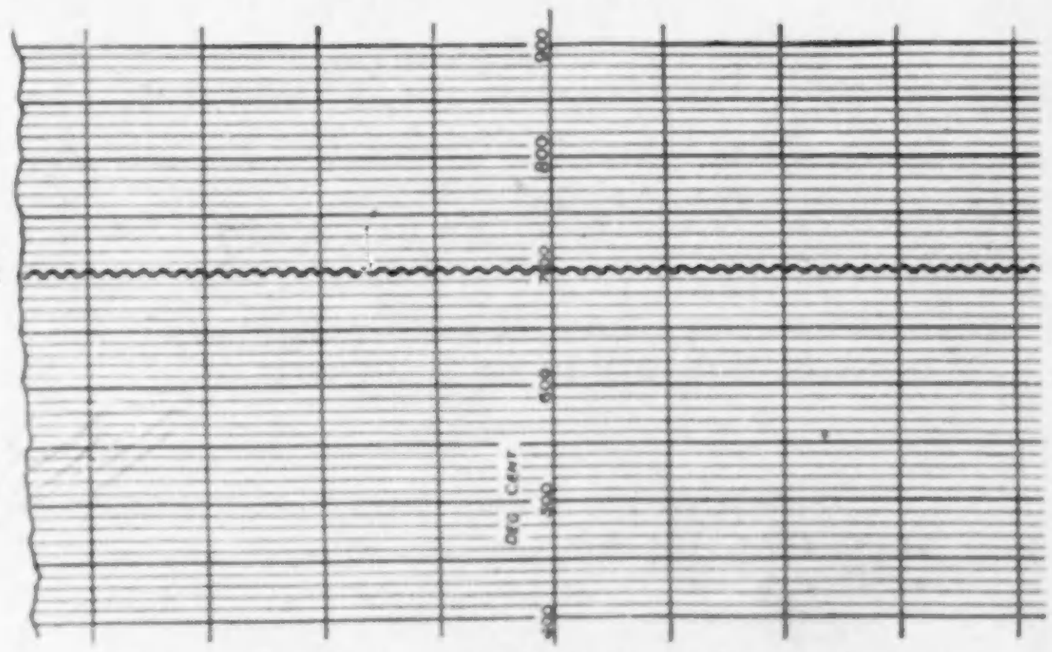


Fig. 5.—Pyrometer record of a large electric furnace automatically controlled.

which entered the furnace through a peep-hole in the door and rested on the hearth. Those in column B were from a thermo-couple which was introduced through the roof 3ft. 6ins. from the door and extended midway between the roof and the hearth. The third couple was introduced through the roof near the back of the furnace and extended 12ins. below the roof. The figures in column D were from a short thermo-couple introduced through the back wall of the furnace near hearth level. The charge consisted of 7½ tons of miscellaneous castings, and hourly readings on the four thermo-couples are given in the schedule.

HOURLY READINGS OF THE FOUR THERMO-COUPLES.

A.	B.	C.	D.
665° C.	665° C.	665° C.	665° C.
730	730	730	730
770	775	775	770
815	815	815	815
870	870	870	870
915	915	915	910
960	960	970	960
1000	1000	1000	1000
1020	1020	1020	1020
1010	1010	1010	1005
1000	1000	995	995
990	985	980	980
985	980	980	975
1010	1010	1010	1005
1010	1010	1010	1005
1000	1000	1000	995
985	975	975	975
950	945	945	945
920	915	915	915
900	900	895	895
885	880	880	880
870	865	865	865
860	855	855	855

ATMOSPHERE.

An electric furnace or oven gives a clean incandescent heat, unaccompanied by smoke, fumes or products of combustion, and consequently, it may be installed in the most convenient position. It is not necessary to consider its position in relation to the location of existing flues or chimney stacks.

The atmosphere inside an electric furnace is susceptible to adjustment according to the process to be performed. Special atmospheres required to facilitate desired chemical reactions can be utilised and maintained with certainty and comparative ease. This feature of control has led to the adoption of electric heating for many purposes for which no other type of furnace has proved suitable.

LABOUR REQUIREMENTS.

In all cases where electric heating is adopted, labour requirements are reduced to a minimum, and in many cases are dispensed with except for loading purposes. With manually operated electric furnaces, a simple switch operation takes the place of the more laborious, tedious and often difficult feeding and regulation of fuel and draught, while with automatically controlled furnaces even this is not required. Electric furnaces are frequently left entirely to the care of automatic temperature

control gear working in conjunction with automatic time switches. A furnace which has been emptied just before the end of a working day may be recharged and left in operation, relying on a time switch to cut off the current at a given time, so that the next morning, the furnace is again ready for unloading and recharging. Similarly, the furnace may be switched off in the evening and reloaded, relying on a time switch to begin the operation at a sufficiently early hour to ensure that the charge shall be ready for handling and further treatment when the operators arrive in the morning.

paid for electrical energy consumed in his works. In many works and for many purposes it is possible to select or design electric furnaces which will have an almost uniform current consumption. This involves careful attention to works organization and to the electrical loading of the furnaces in relation to the work required of them. The effect of so uniform an electrical load of itself tends to improve the overall load factor of the whole works. The extent to which this is achieved depends upon the relation of the maximum demand for heating load to that for general purposes. A

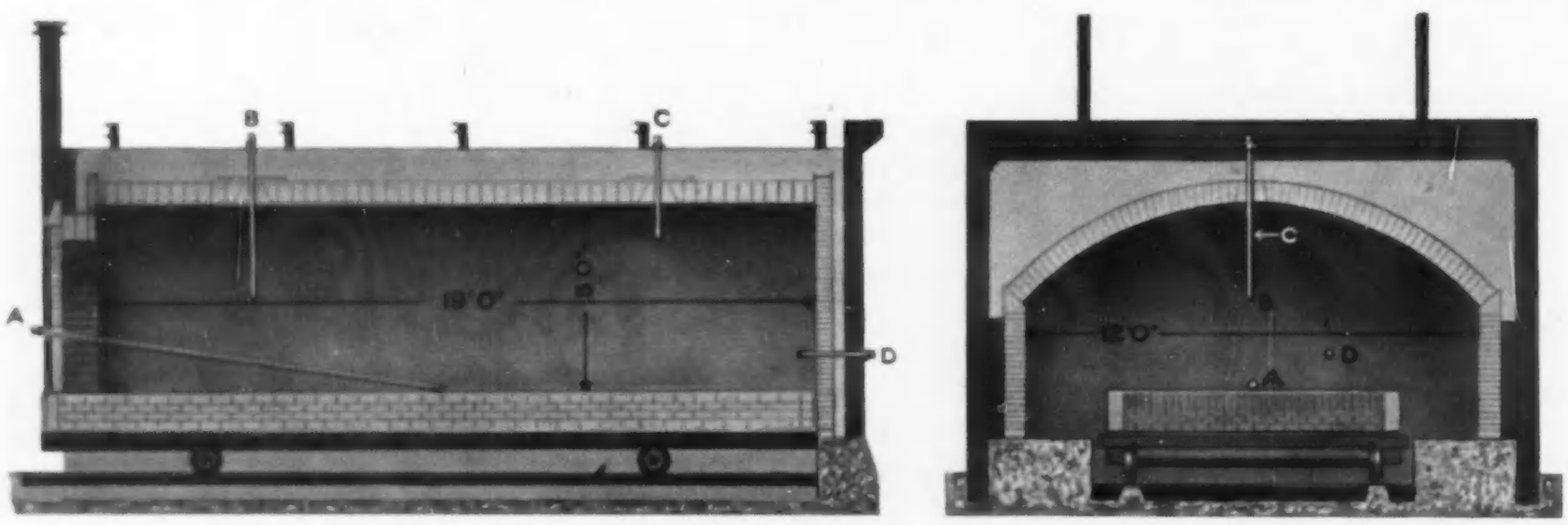


Fig. 6.—Sectional views of electric furnace shewing position of thermo-couples from which hourly readings were taken.

OPERATING CONDITIONS.

The high thermal efficiency of electrically heated equipment ensures the useful application of a large proportion of the total heat generated. Operating conditions are therefore considerably improved, as only a small portion of the total heat is transferred to the workshop and to those working in the vicinity of the furnace or oven.

The space, plant and labour necessary for storing, handling and feeding fuel are saved. Fuel and ash handling frequently involve dust, grime and heavy physical work. Whereas fuel may vary in its calorific value, electrical energy is unvarying in this respect.

Owing to the absence of scorifying flame the refractory lining of an electric furnace has a much longer life than that of a fuel-fired furnace, resulting in a saving of material and labour for repairs, and an increase in the effective or useful life of the furnace.

ELECTRICAL CHARACTERISTICS.

Electric furnaces of the resistance type have a high load factor and offer an ideal load from a central station engineer's point of view, and afford the user a means of reducing the average price

further and important consideration in this respect is the fact that heavily reverberatory electric furnaces may be employed for many purposes. Owing to the large amount of heat stored within the furnaces, they may be switched off to avoid the peaks in the general load, thereby flattening out the load curve and increasing the general load factor of the plant. Similarly, owing to the fact that these furnaces constitute a unity power factor load, their influence on the total plant load is definitely beneficial. Where it is possible to increase the resistance furnace load to a substantial proportion of the whole, the actual saving is considerable.

SUMMARY.

It will be appreciated from what has been said that the inherent characteristics of electric heat are such that an improved and uniform product is obtained. Its reliability is well established and its independence of skilled labour is an important feature, while there are many economic factors which merit earnest consideration. Many users of electric furnaces have found that they could dispense with a subsequent operation which they had hitherto found necessary with fuel-fired furnaces. Incidental advantages such as cleanliness, safety and the reduction of fire hazards are also apparent.

The Testing of Dry Cells.

By R. W. W. SANDERSON, M.Sc.

Research Laboratories of The General Electric Co., Ltd.

For more than fifty years the Leclanché cell in its many shapes and sizes has been an increasingly familiar object both in private houses and in places of business, and despite the introduction of serious rivals, new uses are still being found for it and production is still increasing, while large sums are being spent on its development.

It should be of interest to review the methods of testing an article which is so universally employed.

THE modern dry cell is, in essentials, the same as it was at the time of its inception—that is, a Leclanché cell with an electrolyte immobilised to render it unspillable. Development, although resulting in greatly increased electrical output, has not up to the present proceeded on sufficiently varied lines to make it necessary to differentiate between types of dry cell, which from the point of view of test are substantially the same.

Although the ultimate ideal is to devise tests which reproduce conditions of service, this cannot always be done. Conditions of tests are generally made more severe than those encountered in practice in order to provide a margin of safety, but these conditions of test can only be tightened up by some one very familiar with the characteristics of cells. A test is sometimes made easier in an attempt to make it more difficult, or made so difficult that it gives no useful information.

Tests may be divided into—

(*a*) "Conformity tests" which show whether there is reason to believe that a cell or battery is different from its fellows, and

(*b*) A thorough life test on a representative sample.

CONFORMITY TESTS ON DRY CELLS.

The most usual method of testing a dry cell for conformity with its fellows is that of taking the open circuit voltage, a rapid and simple test. If this test be made a day or two after manufacture it will indicate at once any internal short circuit or other serious trouble.

Another useful test which also involves no hurt to the cell and which will pick out faulty cells which have escaped the first test, is the test for internal resistance. Although for specification purposes, this is accomplished in a manner rather too elaborate for general use as a routine conformity test, a rough measure of internal resistance is given by the short circuit current test.

This test consists of momentarily short circuiting the cell across a low resistance ammeter and, although it appears drastic, it does no permanent harm to a cell. As a real test of excellence for comparing one make of cell with another, this test is quite discredited; its only legitimate use is to detect faults which have occurred during manufacture.

LIFE TESTS ON DRY CELLS.

Assuming that only those cells which have passed the test for conformity are allowed to be placed on the market, there then arises the question of the complete test which will keep a general check on the product and compare it with its competitors. What shall the test be? It is an unfortunate fact that dry cells, unlike many other electrical appliances, may be tested in too many ways. An electric lamp will, in all probability, be used on a voltage the permissible variations in which, although sufficient to cause uncertainty, are at any rate subject to legally defined limits, while a thermionic valve with a filament operated from a battery is not subject to serious variation on that account. A dry cell, however, may, according to the discretion of a user, be consumed completely in any period from a few hours to some time of the order of a year.

This would not be so serious if the designer knew that each type could have its own single test and could devote all his energies to producing a cell to meet it; but the user may in many cases legitimately claim that he is entitled to test the cell in any way he wishes, because the test which he may devise gives him information as to the service he may expect under his own conditions.

STANDARDISATION OF TESTS.

Batteries are used in practice for so many purposes that standardisation of test can only come by mutual compromise and understanding of the difficulties. The great, almost infinite, number of possible tests which result from this insistence of the user on his right to make the test whatever he likes are naturally a great trial to the manufacturer, who may have to test a much larger proportion of his product than is really necessary. He may even make modifications in that part of his regular product which is to fulfil a definite order, merely to comply with a specification which does not necessarily ensure that the consumer obtains satisfaction.

All that can reasonably be expected is that certain arbitrary tests, as few as possible, should be standardised, these corresponding roughly to the most common uses of the dry cell. A user can then choose from these the one which most nearly corresponds to his own practice, and either convince himself that the cell is up to standard specification, or that it is capable of giving better value for money than a competitive type similarly tested. This procedure can only be useful if there is reason to believe that roughly similar tests will sort out a series of cells of the same manufacture at different times, or of different manufactures so that they may lie in the same order of merit. It is possible to prove that this is so, but only by a large series of experiments under very carefully controlled conditions, for individual variations frequently tend to fog the issue.

LIFE TEST CONDITIONS.

The first question that will be asked by the purchaser of a dry cell, or indeed of any article which is consumable, is "How long will it last in service?" In the majority of cases where dry cells are concerned, the user finds that this question is practically unanswerable, because he himself cannot state the conditions of use with any reasonable accuracy. The most important conditions are obviously the time during which the battery is actually discharging in any one day or week and the discharge current required. There are some circuits on which the conditions of service are fairly well established, in that the consumption of current is fairly regular from day to day and week to week, thus enabling the consumer to form a tolerably accurate estimate of his requirements. Cells used for track signalling and telephone work fall into this category. For these purposes, cells are normally purchased in large quantities by big undertakings which are in a position to carry out accurate tests, and to draw up their own specifications. The only complications for the testing departments of the manufacturer arise when two undertakings require tests of only slightly different characters to be made on the same type of cell. This difficulty will disappear with the general adoption of the recently published British Engineering Standards Association specification for "Leclanché Type Primary Cells" in which an attempt has been made to reconcile differences in tests and also in size.

CONTINUOUS DISCHARGE.

It is obvious that a cell may be discharged continuously or intermittently, and that the test chosen should give as near an approach as possible to the conditions occurring in practice.

If, as occasionally happens, the cell is required to discharge continuously during use, or to discharge for so large a proportion of its total useful life as to make the rest period relatively unimportant, a continuous test is indicated and is generally used. On account of its simplicity it is also frequently used even when the anticipated service is rather different.

INTERMITTENT DISCHARGE.

When no approximation to practice can be obtained by a continuous test, an intermittent test must be used, which leads to a need for a further decision as to the type of intermittency, for this too has its affect upon life. Another question has to be considered. Can all consumers (who wish to make tests) make the specified test without expensive apparatus? If, for instance, the intermittency demands so many seconds discharge followed by a rest period of equal duration, then automatic apparatus is required: such a test has been used for many years. If a longer period of discharge is concerned, such as several hours per day, the circuits can, if necessary, be controlled by hand, though here too automatic control is desirable if complete reliability is required. Without automatic control, however, it is inconvenient to make use of a discharge period greater than 8 hours and less than 16 hours per day, as otherwise it becomes difficult to arrange the readings so that they fall in an average working day.

EFFECT OF RECUPERATION.

Assuming for the moment that apparatus for controlling intermittency is available, the question arises as to whether the same result is obtained by, say, discharging a cell for one minute in every six, or four hours in every twenty-four. Actually the output in these two cases will be slightly different owing to the recuperative power of a battery. If the voltage of a battery falls very little on closed circuit it will obviously not need to recuperate, so that batteries which polarise on discharge will often have greater recuperative power than those with good voltage maintenance.

As a very large proportion of the recuperation of a battery takes place very shortly after the circuit is opened after discharge, it is clear that in the case of a battery discharging for one minute in six minutes, rather more effective recuperation will take place than in the other case mentioned. The average voltage during discharge will be considerably higher and the current taken from the cell, except in the very rare case of the current regulated circuit, will be greater. In some cases where the circuit

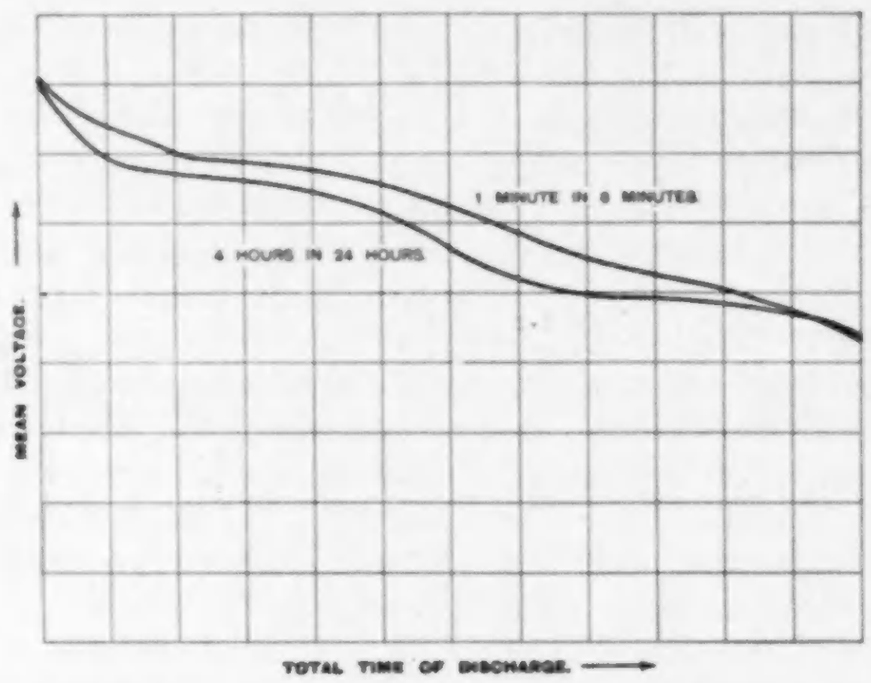


Fig. 1.—Effect of rapidity of alternation of discharge and rest.

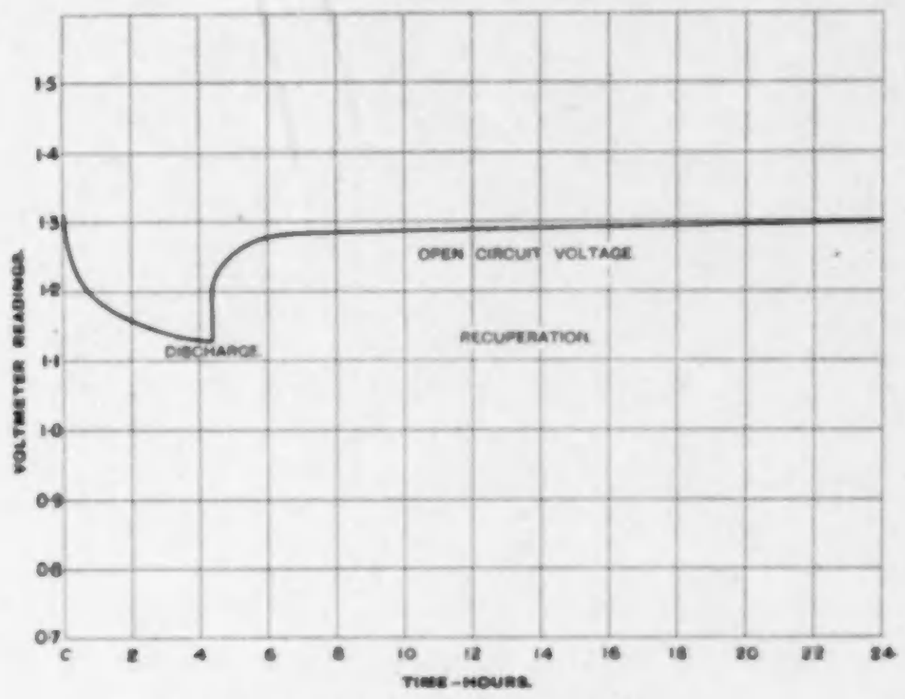


Fig. 2.—Effect of recuperation.

is a simple constant resistance, the diminution in current is not very great, being merely proportional to the drop in voltage. A small, though by no means negligible error will be introduced by a change in the type of intermittency in this case. These points are illustrated in figs. 1 and 2.

Where the plate circuit of a thermionic valve is concerned, the circumstances are rather different and this case will be dealt with later.

It might be argued that if the recuperation takes place fairly rapidly at the beginning of a rest period the total time for an intermittent test might be shortened by making the period of discharge, say, four hours in every eight hours rather than in every twenty-four. This is not quite justified, for in the majority of cases, the resultant shortening of the test would give the battery an advantage in that the effects of shelf test deterioration would be less noticeable (see fig. 3). For most accurate information, therefore, whenever the discharge period per day is approximately known, it should as far as possible be reflected in the test conditions.

Fortunately it has been possible to lay down a period of intermittency which satisfies those who use cells for telephone work and also those who use them on radio receiving sets. This period has been standardised at 30 hours per week with the proviso that the cells may not be discharged for more than six hours in any one day.

In the case of radio receiving sets the period is less than half of the total number of hours during which British stations are working and can be considered to represent heavy use.

Where cells for pocket torch work are concerned, this type of intermittency obviously gives too much work in any one day, and torch cells are, therefore, tested for three hours per week but not for more than half an hour in any one day. Torches are, however, so subject to the whims of their owners, that there is no certainty that any test will bear much relation to the conditions of use.

When the time during which the cell is to be discharged has been established, it becomes necessary to decide on the type of current regulation. There are two main methods; that of constant external resistance, and that of constant current. As may be appreciated from the accompanying discharge curve (fig. 4), these are rather different. Many of the circuits encountered in practice embody constant external resistance, since the cells are installed and left alone until they fail to work. On the other hand, more particularly in the circuits where the cells remain in use for light loads over a long period, and attention is possible, the voltage of a battery of cells may be raised by the addition of extra cells whenever necessary, so that the voltage and hence the current may remain sensibly constant. The former case is frequently associated with the continuous test; the latter with the intermittent. For this and other reasons, the tests which have been standardised are the continuous test on constant external resistance and the intermittent test at constant current. An additional test called the "Heavy Intermittent Test" is also provided for, this being an intermittent test at low constant resistance.

One advantage of carrying out intermittent testing at constant current is that a large number

of cells can be discharged in series with one controlling resistance, the discharge being interrupted by the breaking of a single contact. This does away with the necessity for breaking a contact for every cell tested at some predetermined time, which is necessary where a constant external resistance is concerned. Without arranging for many contacts controlled by one master switch it is not easy to ensure that all the making and breaking of the circuit is effected at the right time. It is, therefore, probable that the heavy intermittent test at constant resistance will not be considered of first importance, except in the case of the torch cells. In this case the test fairly represents a working condition and there is no satisfactory substitute for it.

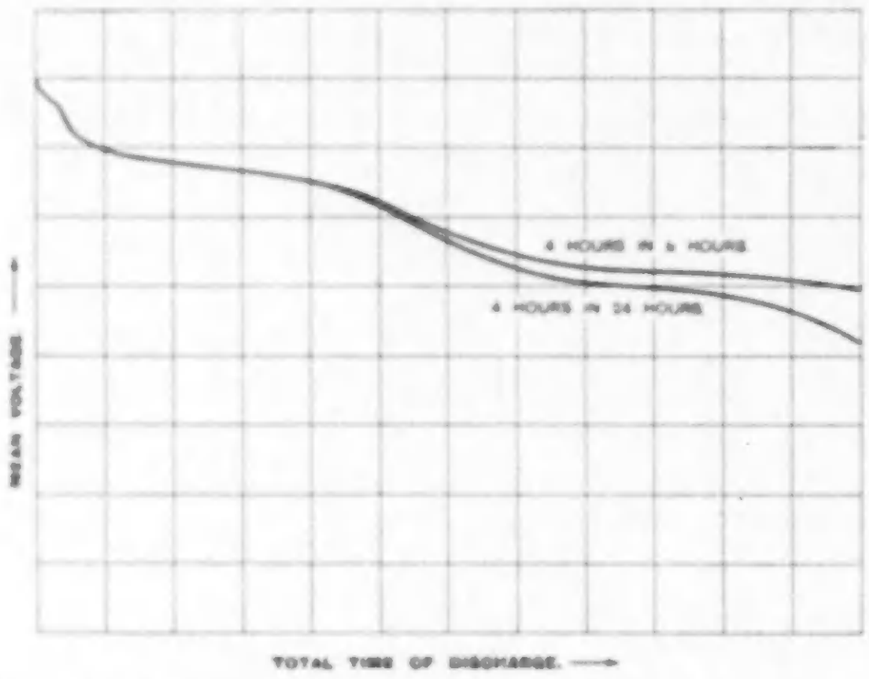


Fig. 3.—Effect of variation in proportion of use and disuse.

RATE OF DISCHARGE.

When such a condition as time of service has been determined, the next consideration is that of the rate of discharge. The Leclanché cell, in either the dry or wet form, is not at its best for heavy discharges, for which purpose it possesses very serious rivals in the lead-acid and nickel-iron accumulators. These, when regularly charged and discharged at frequent intervals, undoubtedly have advantages. As against this, where cells of equal capacity are concerned, the Leclanché dry cell has the advantage in initial cost, in its much greater ability to remain satisfactory in service for very long periods without appreciable loss of capacity, and in its lower weight and small size. Where pocket torches are concerned, the popularity of the dry cell (which is admittedly in this case being discharged at an uneconomically high rate) is due to the fact that it is absolutely non-spillable, and also to the apparent difficulty of making very small non-spillable accumulators which give uniformly satisfactory service.

With the possible exception of the torch cell, the Leclanché battery should not be tested at a rapid rate, such as the discharge at the "Ten hour rate" normally used for accumulators. The standard rates now laid down in the new British Engineering Standards Association Specification, which are in many cases adapted with only slight alteration from previously existing specifications, provide for a test which lasts for about three weeks for the continuous test, about six months for the light intermittent tests on the larger types of cell, and rather less for the smaller types used for radio high tension work.

Where very large numbers of cells of many different sizes and shapes are to be tested, it is necessary in the interests of economy and simplicity to reduce to a minimum the number of values of resistance for the constant external resistance test, and the number of circuits for the light intermittent test. It has therefore been decided that only the following values of external resistance shall be allowable for any cell—2, 5, 10, 20, 50, 100 and 200 ohms—and that the appropriate one to be standardised shall be chosen in such a way that each of the standard sizes of cell shall be discharged at a rate roughly corresponding to size. So that all tests will last approximately the same time. Similarly, there is only a short series of permissible current rates—5, 10, 50, 100 and 150 milliamperes—for the light intermittent test. A complete testing equipment, therefore, requires only seven different types of resistance to be provided, together with six separate circuits for intermittent testing.

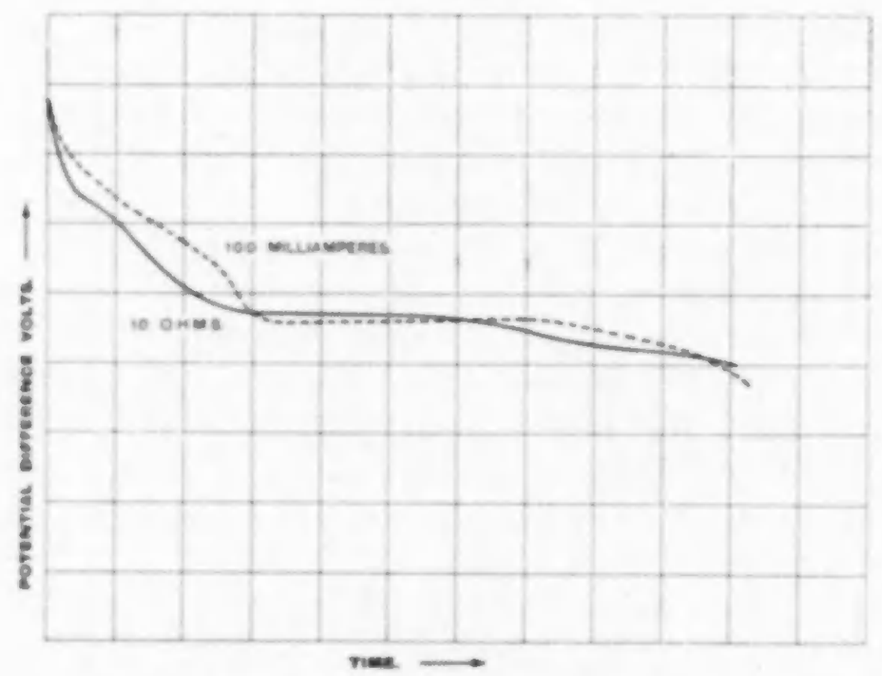


Fig. 4.—Comparison of constant external resistance and constant current discharge curves.

END POINT OF DISCHARGE.

The shape of the discharge curve of a primary cell has become much more familiar to-day than it was a few years ago, owing to the frequency with which such curves are reproduced in battery makers' catalogues and advertisements. An inspection of the curve will show that, unlike the lead accumulator, the Leclanché dry cell has no strongly marked natural end point, though there is a tendency for a cell on

continuous test to fall rather more rapidly when the voltage has diminished to half the initial value than at other points. On intermittent tests the rapid fall often occurs at a slightly higher voltage because the recuperation during periods of disuse enables the cell to maintain its voltage even when perhaps the same amount of work has been obtained as in a continuous test.

Obviously, if a cell is left in circuit for a sufficiently long period it will eventually finish up with a negligible voltage. The cell is useless long before this point is reached. Cells are used for so many different purposes that it is quite impossible to say at what point any apparatus in general will fail to work. Until recently several end-points, each determined for the particular apparatus which the user had in mind, have been in general use, and this has naturally caused a good deal of confusion. In the new B.E.S.A. specification, two end-points are fixed, which although in the nature of things are bound to be arbitrary, are quite reasonable. They are 0.75 volt per cell for the continuous and heavy intermittent tests and 0.90 volt per cell on the light intermittent tests, both measured when the circuit is closed. The end point at 0.90 volt per cell, which is three fifths of the initial voltage, corresponds very well with the point at which a radio receiving set will fail to work satisfactorily if the high tension voltage is correct at the beginning of test.

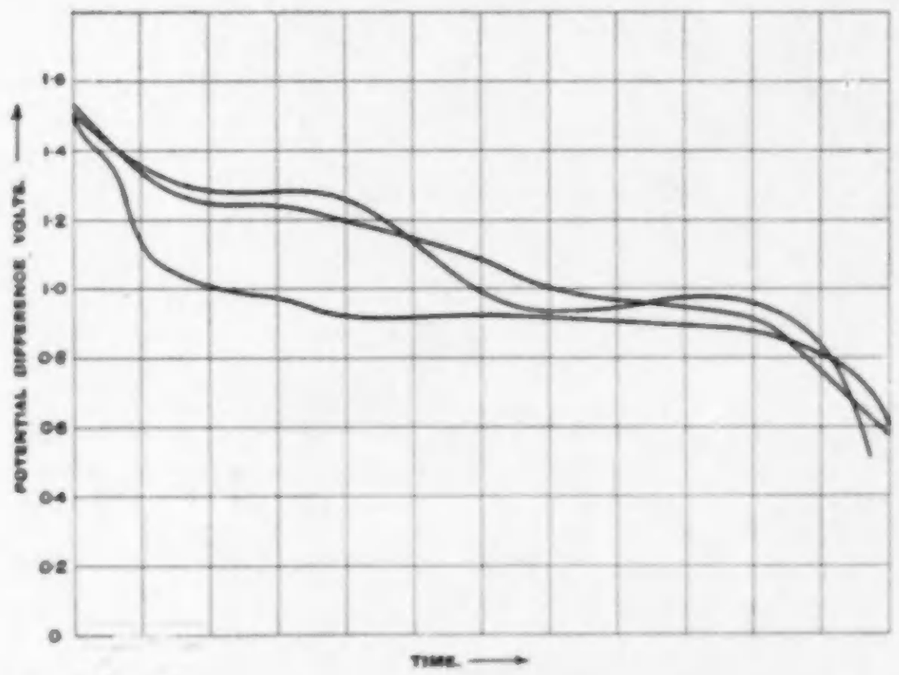


Fig. 5.—Curves showing natural end-point of discharge at half voltage for several different types of cell.

EFFECT OF TEMPERATURE ON TEST.

When the time, rate of discharge, and end-point have been fixed, there still remains the important problem of temperature. The life of a dry cell, except on very light discharge, is materially increased by a rise of temperature of the cell and its surroundings. The temperature coefficient is unfortunately rather variable in amount, not only from one type of test to another or one type of cell to another, but also from one batch to another. It is, therefore, impossible to take life figures at any temperature and reduce them to a standard without considerable risk of inaccuracy. While it is true to say, with some reserve, that the average temperature coefficient is from 1 per cent. to 1.5 per cent. per °F. between the temperature limits of 55° F. to 80° F., it is far better to carry out the testing under approximately constant temperature conditions than to rely on correction. When deterioration as a result of

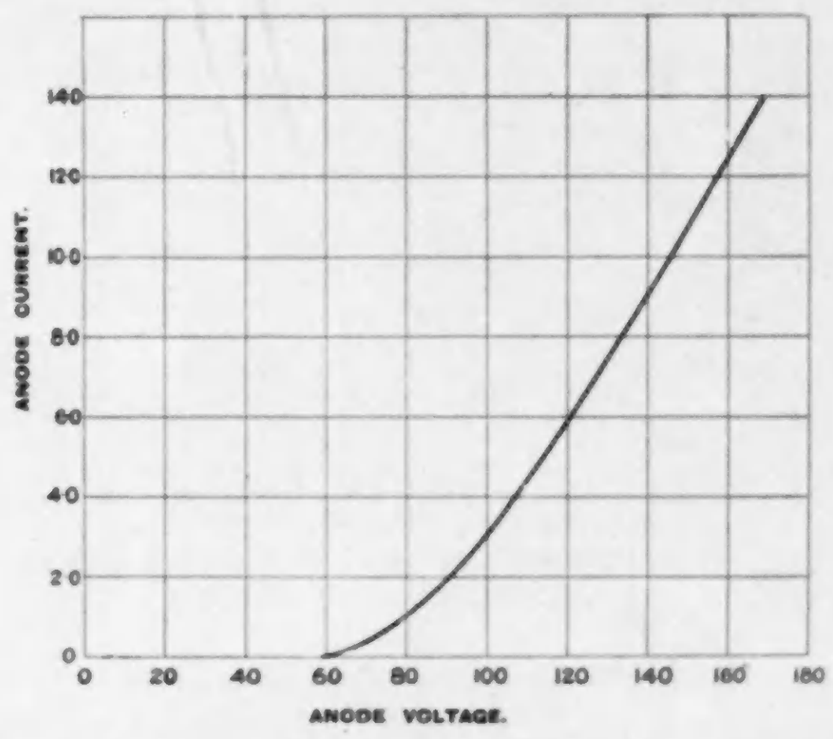


Fig. 6.—Characteristic curve of typical power valve working at fixed grid bias.

storage, usually called "shelf test," is considered, an increase in temperature assists the parasitic actions which result in deterioration, so that a high temperature, while aiding life test, is a disadvantage where shelf test is concerned.

The natural variations in room temperature throughout the year, are quite sufficient to upset the results even of routine works tests, and it is easily understandable that the greater accuracy demanded of results to be used in research and development can only be obtained by close regulation of the temperature. Variations in temperature will swamp many of the small variations which occur as a result of small experimental changes in composition, etc.

When the existing B.E.S.A. specification was being drawn up, it was realised that every consumer or manufacturer could not be expected to construct and maintain an accurately regulated constant temperature room. Figures of output are, therefore based upon a temperature of 60° F. with a proviso that a temperature correction of the value already stated might be applied with caution.

METHOD OF ASSESSING OUTPUT OF CELLS.

Before proceeding to a detailed description of the constant temperature equipment and practical methods of testing in general, the method of calculating outputs should be considered.

It has been customary for various consumers to state their output requirements in several different ways—in days, or hours, in ampere-hours or in watt-hours. The only really satisfactory method, even if it does involve a little extra calculation, is the last. A measurement in time alone has too narrow an application, for if the rate of discharge is varied slightly the output in time varies, while if the output is measured in watt-hours or even in ampere-hours, it causes negligible variation.

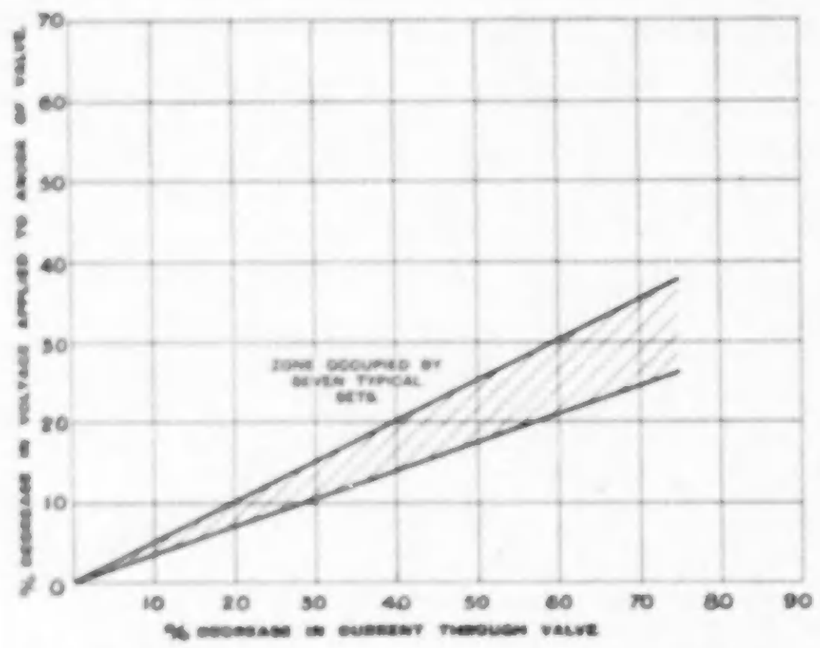


Fig. 7.—Voltage-current characteristics of wireless receiving sets, anode circuit.

Capacity in ampere-hours has been the most usual method of measuring output up to the present time, but watt-hours are a true measure of the work which may be obtained from a cell and form a more scientific basis of comparison. All outputs in the B.E.S.A. specification are now specified in watt-hours.

SPECIAL TESTS.

Reference tests of the type dealt with above must be supplemented in certain cases by special tests designed to give information required for sales purposes. Some of these tests, although tied down to practical conditions even more closely than the specified tests, are far too complicated to be adopted for regular routine tests. An especially difficult problem is presented by the high tension supply to a radio receiving set. An inspection of a valve characteristic, fig. 6, will show that a valve does not behave in the least like a constant current device or a constant external resistance. A practical illustration of this is found in fig. 7 which shows the percentage decrease in current with percentage decrease of voltage for seven typical wireless receiving sets, the total anode current being considered in each case with initial voltage and grid bias recommended by the makers. In the G.E.C. Research Laboratories it has been found useful to install dummy circuits having the same characteristics as wireless sets. These have been arranged to have initial currents of 5, 10 and 20 milliamperes, so that batteries may be tested under repeatable conditions. As the outcome of long experience with sets, the end point has been standardised at 0.90 volt per cell, assuming that full recommended volts are applied initially. The discharge goes on for 30 hours per week as in the standard intermittent test.

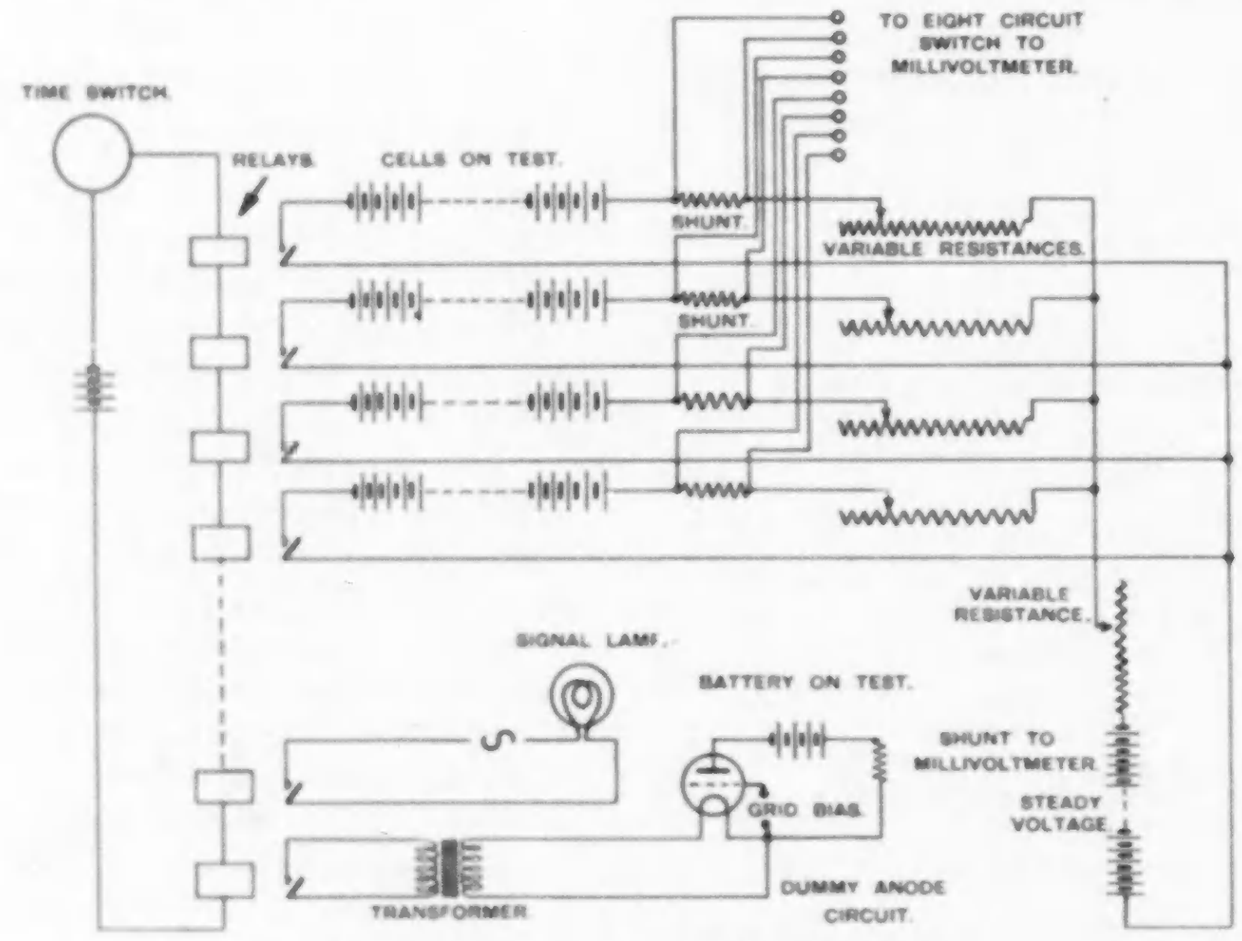


Fig. 8.—Diagram of switching apparatus.

From these circuits, valuable results have been obtained giving direct information on the life of batteries in practice. When these figures are to be applied to sets the difficulty of determining the actual initial anode current of the set at once arises.

Users of wireless sets do not normally adjust the anode current with a milliammeter, while even if the type of valve is known, the inevitable variations from one valve to another make it very difficult to estimate the current which will be taken, even assuming that the anode voltage and grid bias are as laid down in the manufacturer's instructions. No satisfactory system can, therefore, be devised which will enable the life obtainable from any wireless battery to be predicted, even when the type of set is known. All that can be done is to give figures for the average case, and make allowances for variations at least as great as ± 30 per cent.

It may be asked why, if the tests on the dummy circuits give practical results, are they not standardised for routine testing. Actually the variations in characteristics of valves make it difficult to match one circuit exactly with another, while the installation is almost as complicated as a wireless set.

DESCRIPTION OF TESTING PLANT INSTALLED AT THE G.E.C. RESEARCH LABORATORIES.

The necessity for maintaining cells at a steady temperature during test was realised long ago by

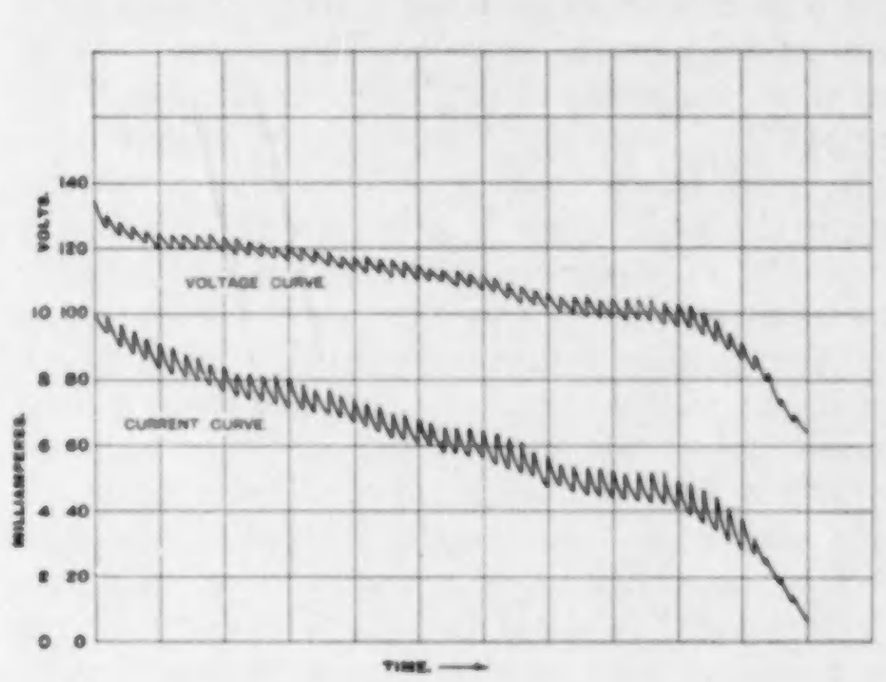


Fig. 9.—Intermittent discharge of wireless high tension battery on wireless set.

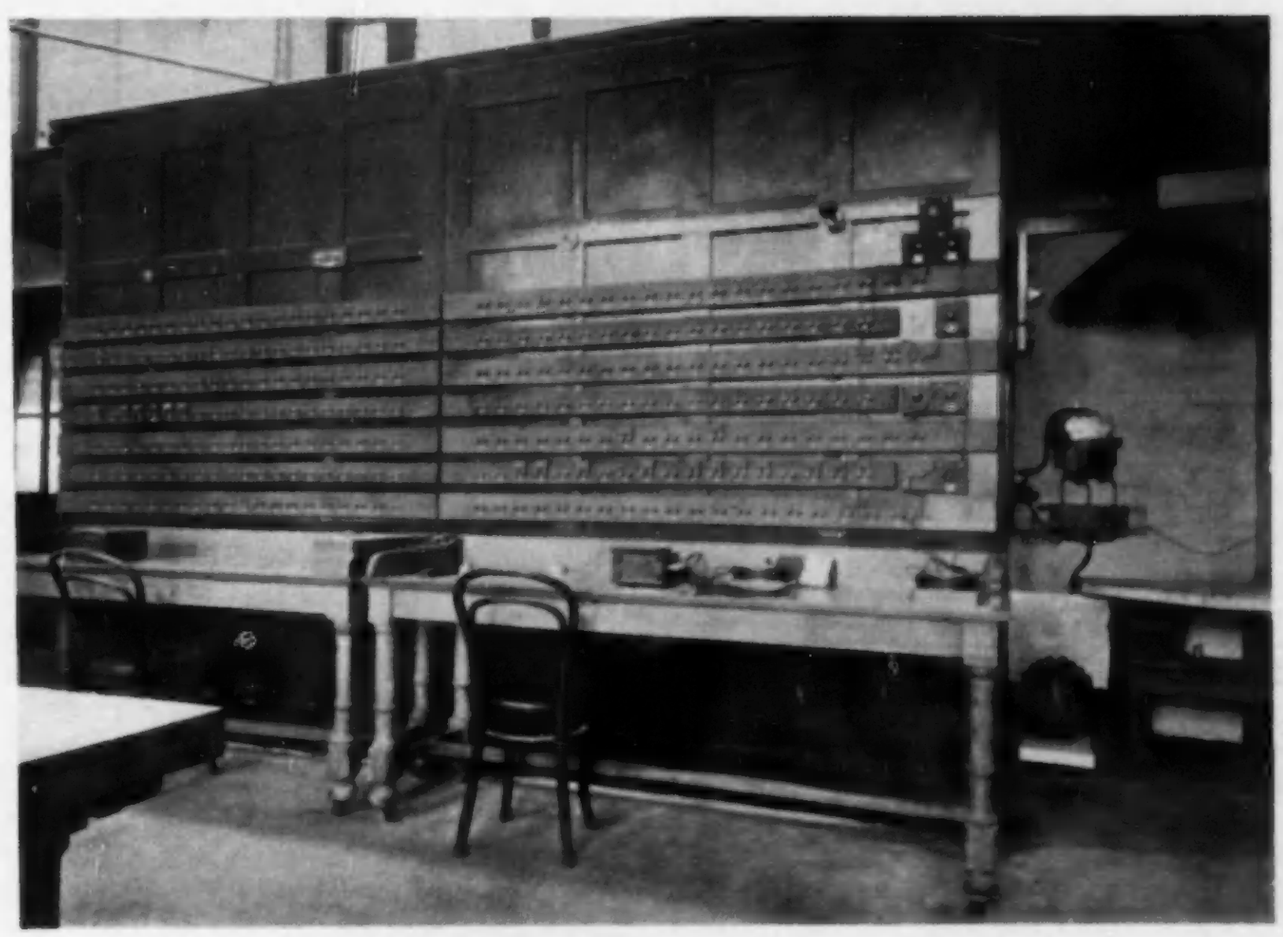


Fig. 10.—One of the constant temperature rooms.

The General Electric Company, Ltd., and two constant temperature rooms were installed. At the time, as no specification existed, a temperature of 25° C. was chosen, largely because this temperature is rarely exceeded indoors in this country, and it was thought easier to maintain a room at a temperature slightly above that of its surroundings than *vice-versa*, heating being simpler than refrigeration.

Some years later it became apparent that this temperature was not completely suitable for tests referring to home-market conditions, since it was only at the hotter seasons of the years that the test data agreed with those of a user if his tests were carried out in this country.

For tests to give results comparable to those obtained in hot countries, it was, on the other hand, very useful.

To come into line with the new specification, therefore, two further constant temperature rooms have been installed, standardising the temperature of the new rooms at 15° C., so that the normal range of indoor temperature in this country is completely covered. For special tests under sub-tropical conditions a smaller enclosure is maintained at 35° C.

The constant temperature rooms referred to have double walls, between which is inserted cork lagging. Leading through these walls are solid copper rods each with a terminal inside and outside the room. These are arranged in pairs, each pair being numbered. The cells are connected across the terminals inside and the voltage measurements are made outside, thus avoiding disturbance of constant temperature conditions which would be caused by exposing the room to outside air. The solid copper rods have been chosen because where the total voltage is only 1.5 volts or less, it is important to avoid any unnecessary drop in voltage owing to resistance.

The spacing between the rods is standardised so that a resistance of standard size and shape may be placed across the outer terminals when constant resistance tests are being made. These resistances are formed of two parallel copper plates with projections which act as terminal strips, bent into alignment and insulated from each other by a strip of bakelite. After assembly of these three parts, the resistance core is insulated and then wound with the appropriate resistance, the two ends of the wire being connected one to each copper strip. These resistances are made accurate to less than 0.5 per cent. (the B.E.S.A. specified figure).

TEMPERATURE CONTROL.

The temperature of each room is controlled by simple electrical thermo-regulators of the toluene-mercury type, and the indications given by these are, in the case of the room at 25° C., transmitted by relays to a heating element, and in the other, to an electric refrigerator which circulates cooled air. Adequate ventilation is ensured in each case by the use of electric fans. The regulation has been found by thermograph charts to be within 0.2° C., which is sufficiently accurate.

AUTOMATIC CONTROL OF DISCHARGE.

The intermittent tests are controlled by master time switches which actuate a series of relays, each of which controls one of the intermittent circuits, fig. 8. As may be seen from the diagram, fig. 9, for any intermittent discharge there is a small drop in voltage from the beginning to the end of each day's discharge period. This will involve a small change in current which must be corrected at intervals. If, in series with the cells on test, a fairly high steady voltage and constant resistance are added, this drop will be minimised and may be subject to less frequent corrections, as a lower proportion of the voltage in the circuit is variable. It is normally arranged that about two-thirds of the voltage in the circuit is invariable.

The actual current is indicated by a millivoltmeter which is connected by means of an eight way switch across a series of shunts, one placed in each intermittent circuit, and so arranged that all readings are at the same point of the scale. Any small variations are controlled by a series of variable resistances. As it is important that tests should be made as soon as the circuit is completed and just before it is broken, a series of warning lamps are operated by the same master switches.

The method of test is that of reading and recording potential differences across the terminals of the cell at predetermined intervals, generally daily, and by integration of the area enclosed by a curve drawn from these readings, obtaining data for a determination of the output in watt-hours. As the discharge currents of primary cells are often rather low, it is important that errors should not be introduced by carrying out tests with low resistance instruments. The B.E.S.A. specification, therefore, provides for a voltmeter of British standard first-grade accuracy with a resistance of not less than 500 ohms per volt of scale, and with a minimum total resistance of 1,000 ohms.

In the case of the dummy sets for testing wireless high tension batteries, the filaments are operated from alternating current supplied from a transformer, the primary of which is again controlled by the master switch, while the grid bias is taken from a constant external supply.

WIRELESS BATTERIES.

It may be thought that undue emphasis has been laid upon the case of the wireless high tension battery, but in view of the fact that approximately 350,000,000 single units are sold every year in Great Britain alone, they cannot be regarded as unimportant. They present features of special interest, not only in the methods of test owing to the unusual characteristics of the circuits on which they are used, but also because they form an interesting example of the metaphorical chain, the strength of which is that of its weakest link. This is one of the rare cases in which an assembled article is made with completely irreplaceable units and depends for its life equally upon all the constituent members. In each battery there are from 40 to 70 single units and a manufacturer who can by control ensure that not more than 0.02 per cent. of his product will give a shorter life than the average, will still have to face the problem that 1 per cent. of his batteries may fail early.

The standard of quality must, therefore, be exceptionally high in order to obtain satisfactory results.

The Electrification of a Wax Battik Printing Factory.

By F. BARLOW, A.M.I.E.E. G.E.C. Resident Engineer, N.W. England,
and
D. C. ROGERSON, B.Sc., Witton Engineering Works of The General Electric Co., Ltd.

The electrification of a wax battik printing factory not only affords another instance of the versatility of the electric drive, but is also indicative of the widespread movement in industry towards electrification.

In this particular instance the change-over from steam to electricity has been effected in surroundings of more than usual interest, and a brief description of the fascinating processes carried out in the factory of the British Block Printing Co., Ltd., should be of interest.

THE British Block Printing Co., Ltd., whose factory is situated at Disley, near Stockport, was first formed in 1914 for the production of a special form of printed calico which is exported solely to West African markets.

The Company first rented an old mill which within seven years was enlarged to double its original size. During this period all the machines employed for the various processes were steam driven. Towards the end of 1928, however, the factory was completely gutted by fire in 2½ hours, the conflagration being considerably accelerated by reason of the large quantities of resin used in the printing processes. A new building was subsequently erected on the site of the old, and is of a completely fireproof nature; the walls and supports are of reinforced concrete, with sheet steel doors separating the different departments.

Adjacent to the new building is a boiler house, which provides superheated steam for a back-pressure engine driving a 100 kW generator, the exhaust steam being used for process work in the factory. The generator supplies direct current at 230 volts, and is controlled by a 2-panel slate switchboard. A private reservoir, situated close to the factory, supplies the necessary 40,000 to 50,000 gallons of water a day.

During the time of reconstruction the opportunity was taken of converting all the drives from steam

Fig. 1.—The waxed material passing through indigo dye vats. The 10 h.p. motor driving the rollers may be seen in background.

to electricity, and it is noteworthy that this has resulted in an increased output of 100 to 150 per cent. All the electric motors employed are the standard D.C. protected type. These and their control gear are shown in the accompanying illustrations. The motors range in size from 8 h.p. to 30 h.p.

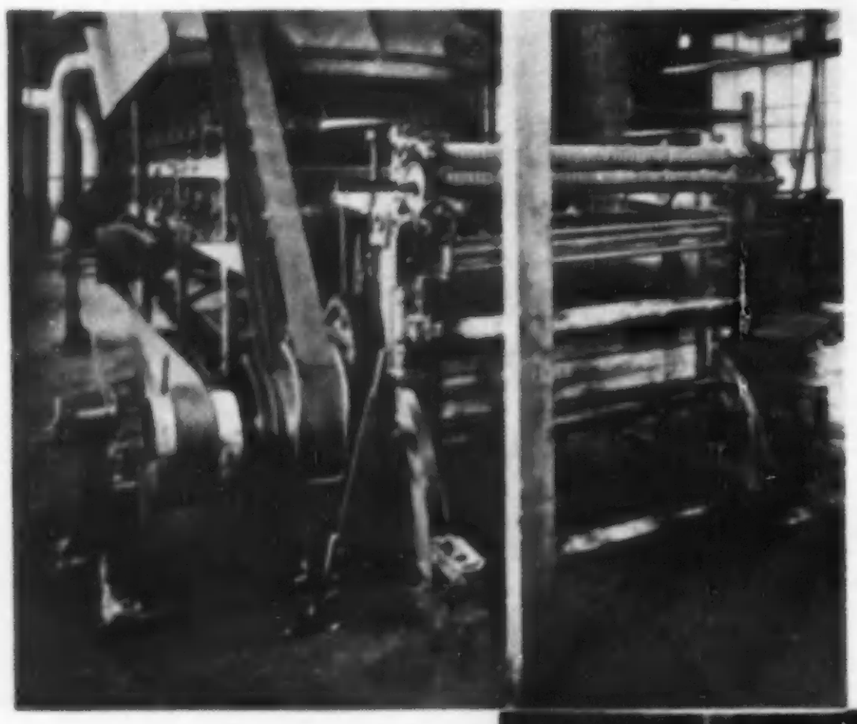


Fig. 2 (*Above*).—**Drying machine through which material is passed after preliminary washing.**

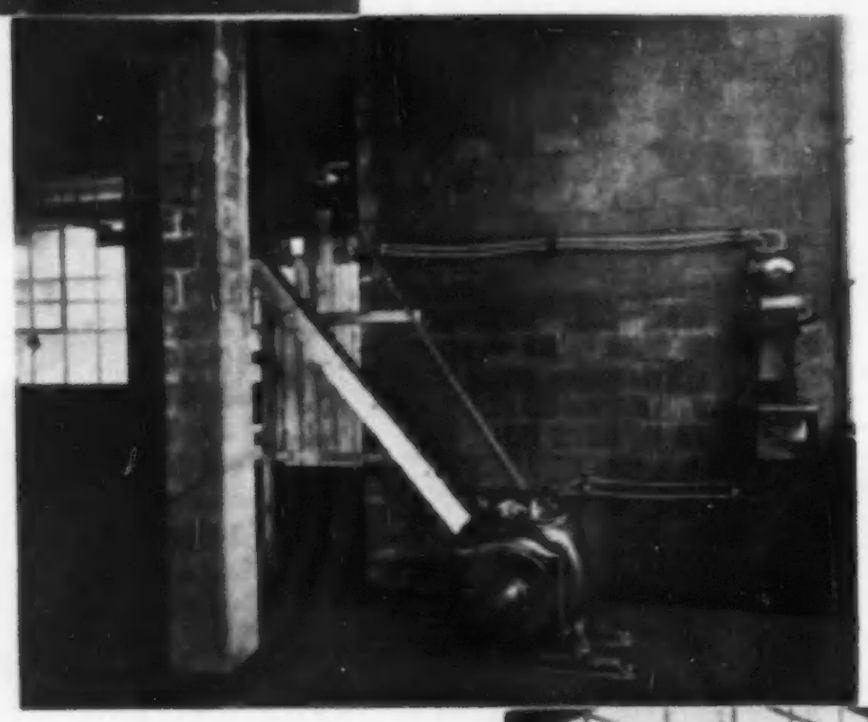


Fig. 3 (*Right*).—**20 h.p., 600 r.p.m. D.C. motor driving drying machine.**

THE ORIGIN OF WAX BATTIK PRINTING.

The process employed in the dyeing of the calico is known as "wax battik printing" and is of a particularly interesting nature, well worthy of a brief description.

The natives of West Africa clothe themselves in a hygienic if primitive manner by wrapping round their bodies a few yards of brightly coloured material which, originally, was crudely hand painted by the natives themselves, the finished product, known as "Battik," being judged not so much by its artistic conception as by its garish colouring. During the hand painting of the pattern on lengths of the raw material it was inevitable that flaws appeared where different colours overlapped or failed to meet, and that no two repetitions of the pattern on the same piece of cloth were identical.

These flaws the natives regard as a *sine qua non*, and, consequently, machine printed material, with its perfectly registered colouring and its precise repetition of the pattern, is regarded as a poor substitute and finds no easy sale. Indeed, it is impossible to produce the native battik form of material purely by machine, the most successful commercial process finally evolved being known as "wax battik printing."

INITIAL PROCESSES.

In this process as carried out at the factory of the British Block Printing Co.—one of the few British firms engaged in this work—the raw material as it comes to the factory consists of grey cotton cloth in two widths, 36 inches and 50 inches. This is first immersed in a Croft washing machine to remove dressing and other impurities and is then bleached, both these processes taking place in the Bleaching House, the machinery of which is driven by a 10 h.p. 340 r.p.m. motor situated in an adjoining room.

The cloth is then opened out to its full width by a scutching machine and dried by passing the entire length over the steam heated rollers of a large drying machine, both machines being belt-driven from shafting by a 20 h.p. 600 r.p.m. motor. A view of the drying machine is shown in fig. 2, while the 20 h.p. motor and its control gear are illustrated in fig. 3. The motor starting panel of this and the other fixed speed motors consists of a totally enclosed combined ironclad air break switch and fuses, ammeter and starter mounted on an angle iron framework which is bolted to the wall, the ammeter providing a convenient check on the current taken by the motor.

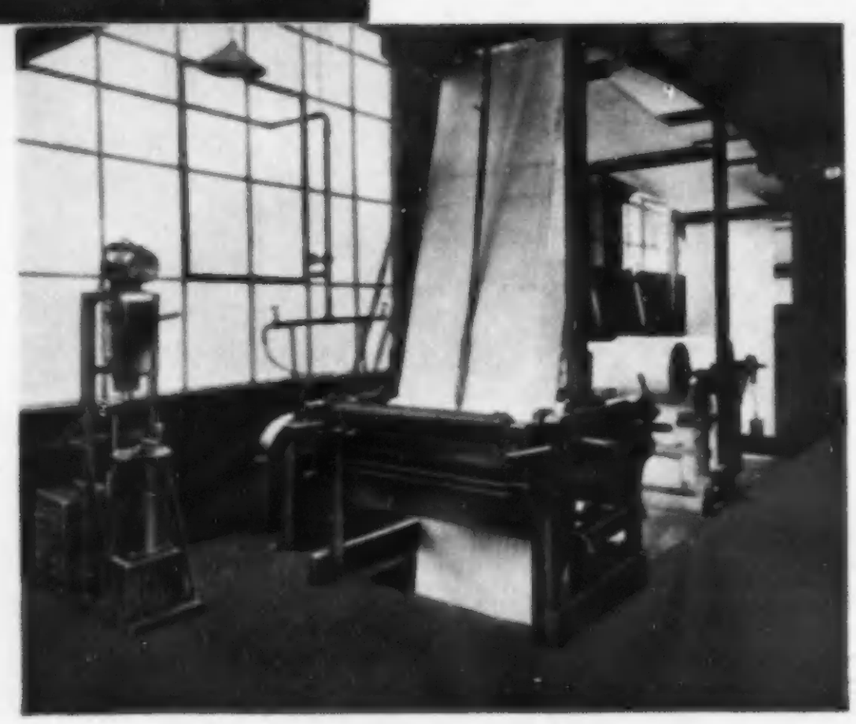


Fig. 4.—One of the waxing machines, showing the motor control gear.

WAX PRINTING

The next stage, in which the material is taken to two waxing machines, is particularly interesting. Here the cloth is passed between copper rollers on which a pattern has been hand engraved by skilled labour employed on the premises. These rollers rotate partially immersed in molten wax and impress the pattern in wax on both sides of the cloth. One machine deals with the 36-inch width of material and the second machine with the 50-inch. Each machine is driven by an 8 h.p. variable speed motor with a speed range of 300/750 r.p.m. One of the waxing machines with its control gear is illustrated in fig. 4, while fig. 5 shows the other waxing machine and its driving motor. The variation in speed of the motors is obtained in each case by a drum type controller in conjunction with a separately mounted resistance, giving one "off" and several running positions.

APPLICATION OF FIRST COLOUR.

This waxing process is a most important stage, requiring great skill and experience on the part of the operator, for it is on the correct application of the wax, involving a nice judgment in the speed of the rollers and the condition of the wax, that the success of subsequent stages depends. The purpose of the wax is to allow the indigo dye, which forms the background to the final colour scheme, to permeate only those portions of the material uncoated by wax. The coated portions, which will subsequently receive a different colour, remain undyed. The first colour application is accomplished by slowly passing the waxed cloth through a series of six

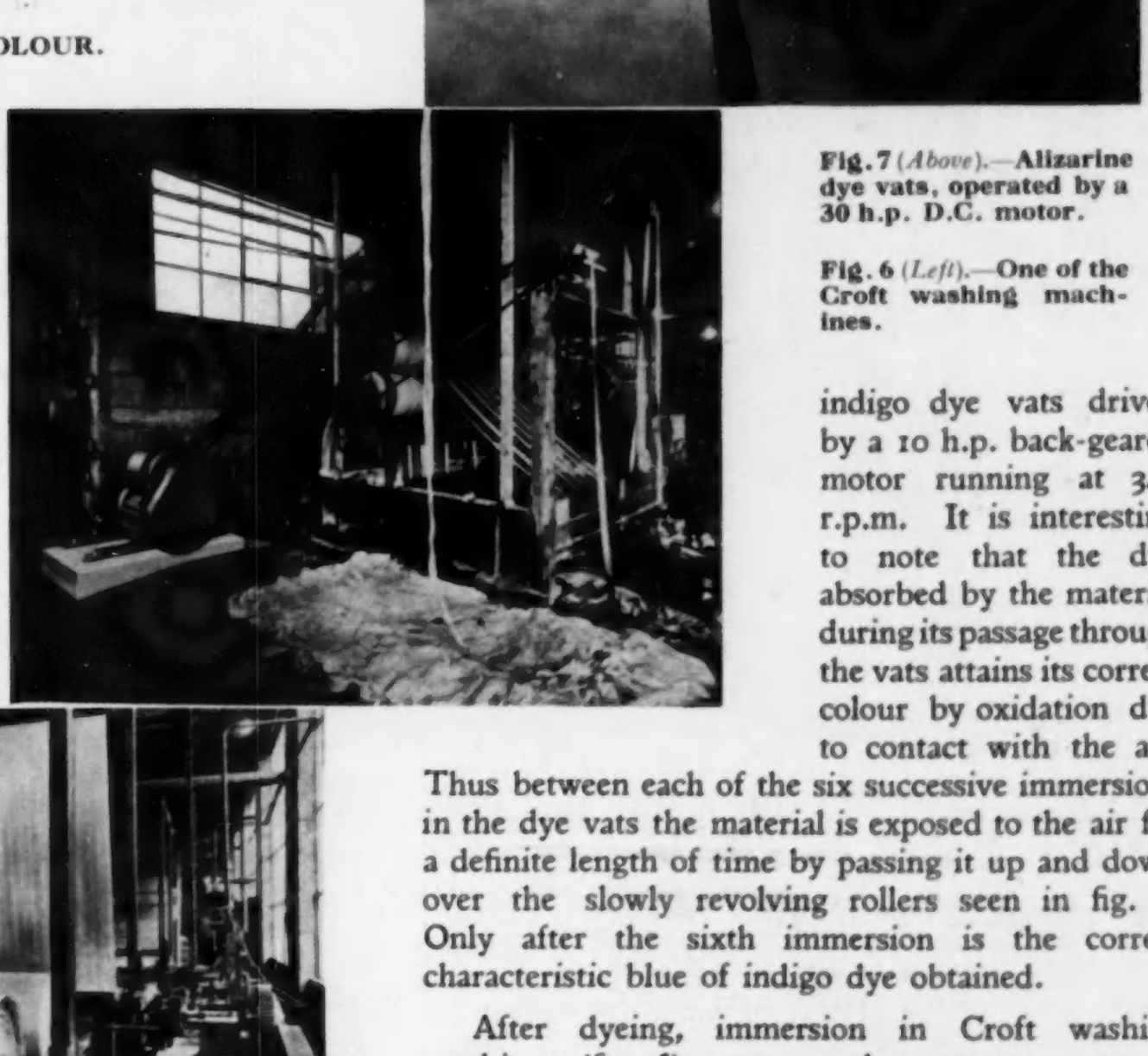


Fig. 7 (*Above*).—**Alizarine dye vats, operated by a 30 h.p. D.C. motor.**

Fig. 6 (*Left*).—**One of the Croft washing machines.**

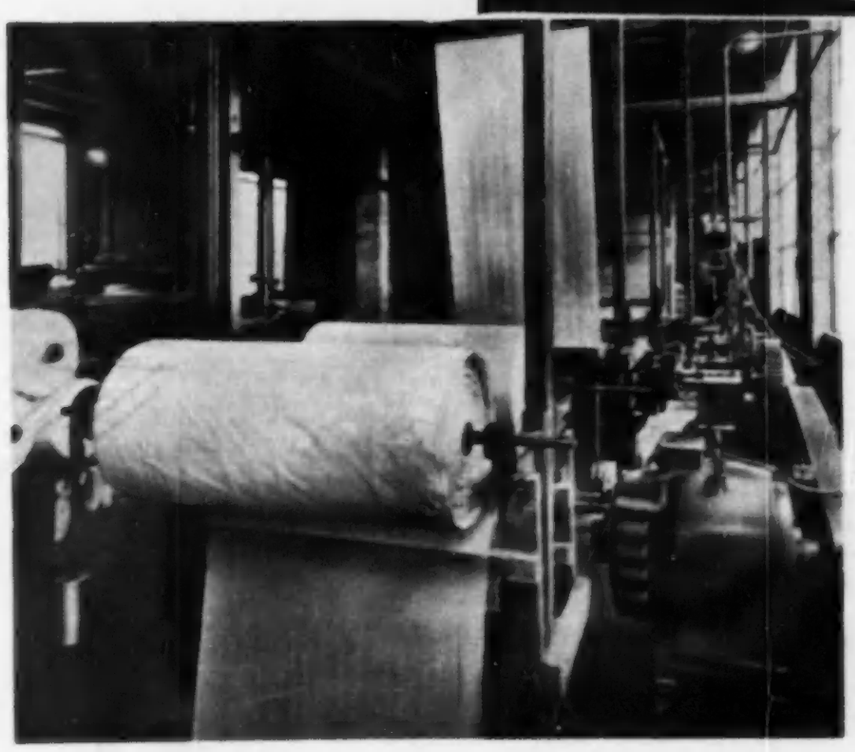


Fig. 5.—Another view of a waxing machine, driven by an 8 h.p. variable speed D.C. motor.

indigo dye vats driven by a 10 h.p. back-geared motor running at 340 r.p.m. It is interesting to note that the dye absorbed by the material during its passage through the vats attains its correct colour by oxidation due to contact with the air. Thus between each of the six successive immersions in the dye vats the material is exposed to the air for a definite length of time by passing it up and down over the slowly revolving rollers seen in fig. 1. Only after the sixth immersion is the correct characteristic blue of indigo dye obtained.

After dyeing, immersion in Croft washing machines (fig. 6) removes about 50 per cent. of the wax, the remainder still adhering to the material giving the desired broken effect to the pattern, as explained at a later stage.

A hydro-extractor, belt-driven from shafting through a cone friction drive removes about 75 per cent. of the washing water by centrifugal action. Both of the Croft washing machines used at this stage, the hydro-extractor, and the alizarine dye vats employed at a later stage are driven through shafting by a 30 h.p. motor at 300 r.p.m. This is seen in fig. 7.

APPLICATION OF SECOND COLOUR.

At this point the pattern has received one colour only. The application of the second colour is accomplished by hand in what appears to be a crude manner, but it must be remembered that such crudity is aimed at and is an essential quality.

The colour is applied by means of wooden blocks the faces of which are cut by hand to a pattern identical with that to be coloured on the material. As the pattern usually repeats itself at frequent intervals, only a comparatively small block is required, and this is dipped into a "prepare" of mordant and carefully applied to the material so that the block registers with the pattern. For this purpose the material is laid out on a long bench, and as each section of a roll is finished the operator hangs it in a large drying compartment and proceeds to block in the next section. The particles of wax still adhering to portions of the pattern prevent the second colour from being applied evenly, thus producing the broken effect which the natives consider so desirable.

After drying, the "prepare" of mordant is "fixed" by immersing the material in a soaping machine driven by a 30 h.p. motor running at 300 r.p.m. It should be explained here that the "prepare" does not, of itself, dye the material, the actual colour being developed up in "alizarine" dye vats in which a chemical action takes place between the mordant on the material and the liquid in the vats to produce the required colour.

FINISHING PROCESSES.

A final washing to remove all traces of wax is carried out and the material is then dried in the large drying machine previously mentioned.

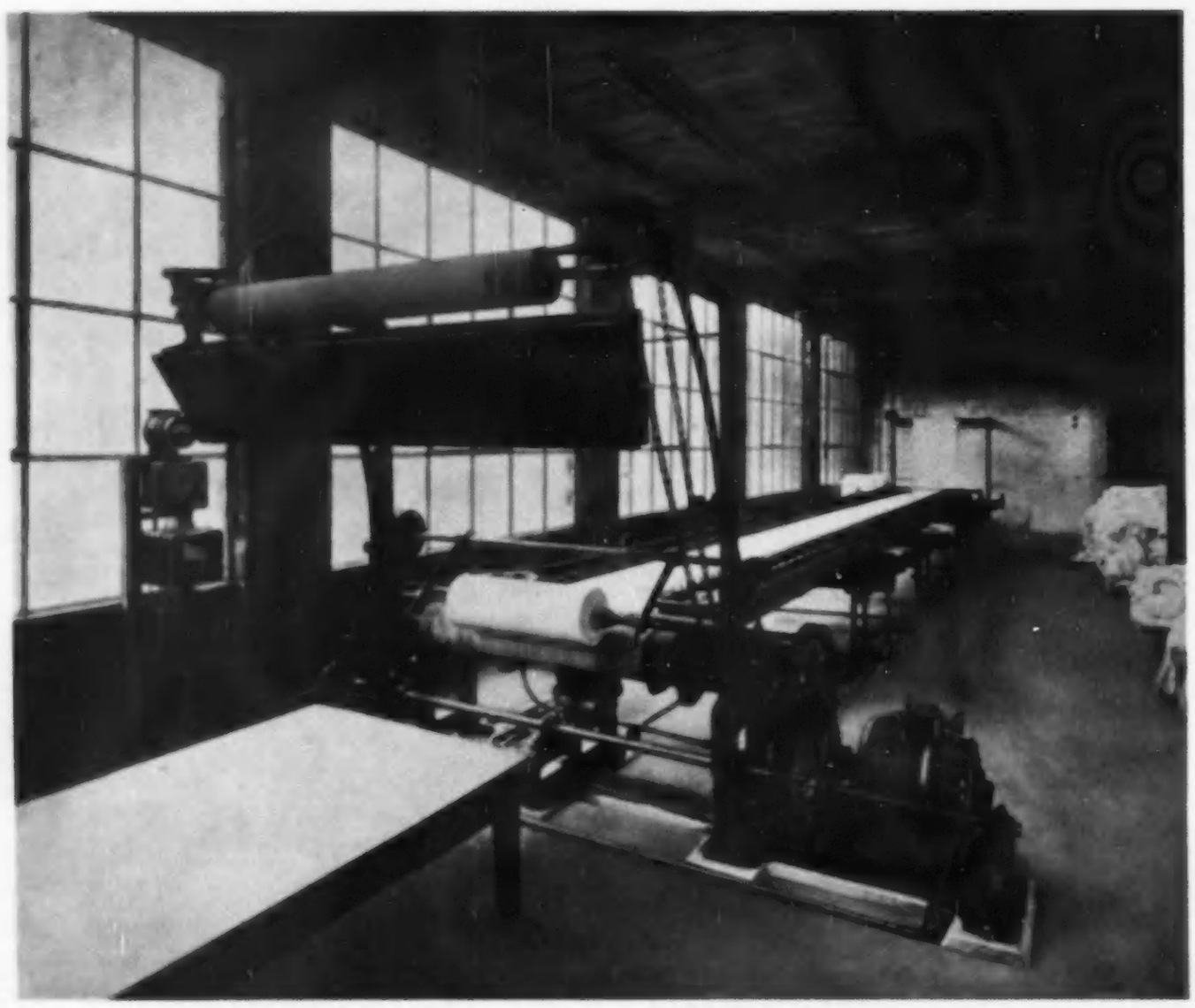


Fig. 8.—Stretching and finishing machine, geared to an 8 h.p. D.C. motor.

During these many processes the material has shrunk slightly in width and the final process consists in passing the entire roll of material through a stretching and finishing machine driven by an 8 h.p. variable speed motor. This ingenious machine, illustrated in fig. 8, restores the material to its original width and removes any creases that have been produced through handling.

This completes what is of necessity a brief outline of the interesting and, in many cases, intricate processes involved in the making of a battik printed material. It remains for us to acknowledge our indebtedness to Mr. Leslie H. Harrison, Works Manager of the Company, for his courtesy in placing facilities at our disposal for inspecting and photographing the equipment described.

The Design of High Power Heavy Oil Engines.

By G. A. MELLOR, A.M.I.Mech.E.,
Oil Engine Dept., Fraser & Chalmers Engineering Works of The General Electric Co., Ltd.

The first heavy oil engines which Fraser & Chalmers introduced many years ago embodied a number of features in design which had previously been considered impracticable, but which became possible by careful design and a choice of suitable materials.

The manner in which the various problems were tackled and their eventual solution form a very interesting study. The author here describes the principal features of the Fraser & Chalmers oil engine and gives a few of the experiences met with during their operation in commercial service.

UP to the year 1920 the maximum power produced by any single oil-engine cylinder was 125 b.h.p. This was obtained with a cylinder bore and stroke of 20 ins. and 24 ins. respectively and a flywheel speed of 200 r.p.m., and was equivalent to 750 b.h.p. from a six cylinder engine of the four cycle type used for generating electricity for land power station duty. In contrast to this, the modern oil engines which it is proposed to review in this article, develop 275 b.h.p. per cylinder with a bore and stroke of 21½ ins. and 22ins. respectively, and at a flywheel speed of 300 r.p.m., representing an increase of 120 per cent. in flywheel speed, and a normal load of 1,650 b.h.p. in a six cylinder engine. Previous to 1920, the possibility of such a large increase in power was viewed with a certain amount of scepticism by users and makers alike, and before any such progress could be made it was necessary to investigate metals which would not only permit of rapid heat flow without setting up abnormal heat stresses, but which would also provide more durable wearing surfaces than cast iron, the orthodox metal used in the class of engine then in vogue.

Cast-iron is, of course, still used in some makes of oil engine to-day, primarily because of its cheapness and its excellent rubbing qualities, although failures of this metal for cylinder liners, pistons and cylinder heads have been consistent and frequent ever since oil or gas engines were made. Its continued use is, however, justified by improvements which have been made in the mixture and strength of the iron used, and by more scientific foundry practice. Further, to mitigate the inherent weakness of cast-iron when subjected to heat, excellent attempts have been made to modify previous designs; failures have also become less frequent because cylinder ratings have been reduced, thus prolonging the life of the metal around the combustion space.

That the root cause of many disasters could be traced to the use of cast-iron was well known, but, even so, the introduction of any other metal as a substitute was viewed with uncertainty and prejudice. After a careful study of different metals, however, it was discovered that, although the new materials investigated were more costly, it would be possible by their use not only to increase the output of a cylinder by 33 per cent. per cubic inch displacement, but also to lessen the stresses in the materials.

It was also found that the gain in output, together with the increase in metal durability, more than counterbalance the higher cost of the superior metals. When put into effect, the result of this policy proved to be most satisfactory, and engines of the new type, aggregating 18,000 b.h.p. have already been built, while in one London power station alone, oil engines totalling 8,000 b.h.p. in capacity represent the largest installation of this nature in Great Britain. An engine of this type was also for some time the first and largest to be installed on land in this country.

THE MODERN ENGINE.

The principal data of the standard cylinder unit for the engines under review are as follows :—

B.H.P.	275.310
B.H.P. per square inch of cylinder bore	.76–.85
I.H.P.	350–400
Fuel consumption per b.h.p./hour	.39–.405 lbs.
R.P.M.	300
Fuel consumption per sq. inch of cylinder bore per hour ..	.295–.343 lbs.
Diameter of cylinder	21½ ins.
B.T.U. per sq. inch of cylinder bore per hour, assuming 18,000 b.t.u. per lb. net	5,300–6,200
Stroke	22 ins.

M.I.P.	120–136 lbs. per sq. in.
Mechanical efficiency	77 per cent. to 79 per cent.
Mean piston speed	1,100 ft. per min.
Swept cylinder volume	4.63 cu. ft. per stroke
Crankshaft diameter, pins and journals	12 ins.
Length of connecting rod ..	56$\frac{13}{16}$ ins.
Ratio of rod length to crank throw	5.17 : 1
Weight per b.h.p. with flywheel..	180 to 200 lbs.

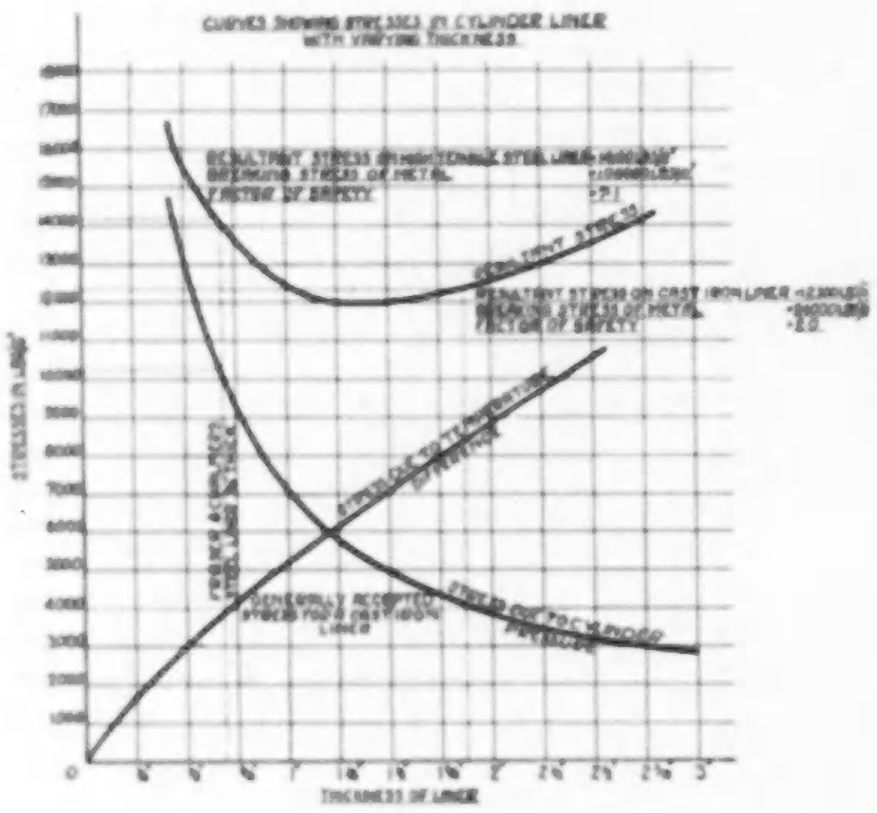


Fig. 1.—Temperature and load stresses in high tensile steel and cast-iron liners.

A prime mover to-day must be economical both in regard to fuel and lubricating oil, and in spite of the fact that higher piston speeds and higher rotating speeds had previously produced higher consumptions of fuel and lubricating oil, yet it was felt that results relatively as good as those of the slower speed engine would ultimately be achieved as experiment and experience proceeded. Results to-day show that in these respects the modern engine compares in performance with the best of the slower speed units.

It had been presumed, and not without justification, that higher speeds and higher rating raised the maintenance cost; the problems of obtaining reliability, and at the same time manufacturing for a competitive market, were thus of great interest and not without difficulty.

CYLINDER LINERS.

To obtain the efficiency aimed at, all parts subjected to the temperature of combustion were made as thin as was consistent with ample strength. As an example, the cylinder liners were made of high tensile toughened steel, the thickness being 16mm. (11/16-in.), so as to eliminate heat stress by maintaining a low temperature difference.

Had a cast-iron liner been adopted, the thickness would have been about 2 ins. and a correspondingly high temperature difference would have existed between the inner and outer surfaces. This would have had a detrimental effect on the liner bore when dealing with the quantity of heat generated for so high an m.i.p.

The curves shown in fig. 1 illustrate the stresses due to temperature and load in high tensile steel and cast-iron liners, and the factor of safety obtained by adopting steel.

When designing the liner due regard was given to the following :—

1. Complete circumferential cooling at the combustion end.
2. Uniform distribution of the water to the cylinder cover.
3. No bending stress in liner due to screwing-down load of cylinder cover.
4. Accessibility to the water spaces around the liner when the cylinder head is removed.
5. Possibility of repairing a liner when wear-down, due to the rings, renders it inefficient for working.

It is well known that in large engines the rate of wear in cylinder liners is more rapid than in smaller sizes.

In heavy duty trunk piston engines particularly, the cylinder liner should be made of the best heat-resisting metal having a high coefficient of conductivity. Further, the metal must be that best able to resist the abrasive action of carbon and ring pressure when under the influence of combustion.

Liner wear is chiefly due to :—

1. Inefficient lubrication.
2. Corrosion.
3. Unsuitable material for wearing surface.

The factors (1) and (2) are more troublesome as temperature is increased, their influence on wear being of logarithmic form. It is therefore essential that there should be as small a temperature difference as possible across the liner wall, while a low wall temperature is also essential if high volumetric efficiency is to be attained.

A cast-iron liner for a cylinder of 21½ ins. diameter would certainly not meet these requirements with regard to factor (3). Cast-iron is usually more or less porous and loose on the surface and can only be expected to resist wear when rubbing pressures are low and lubrication good.

At the top end of a cylinder liner, rubbing pressures are high and lubrication seldom good;

it was therefore considered that a thin steel liner with a hard surface would give better service. Results have proved this view to be correct. A comparison of the steel and cast-iron construction, is illustrated in figs. 2 and 3.

It has been found that out of 51 liners in commission, one in a four-cylinder engine, after about 8,000 hours' running at ¾ full load, has an average

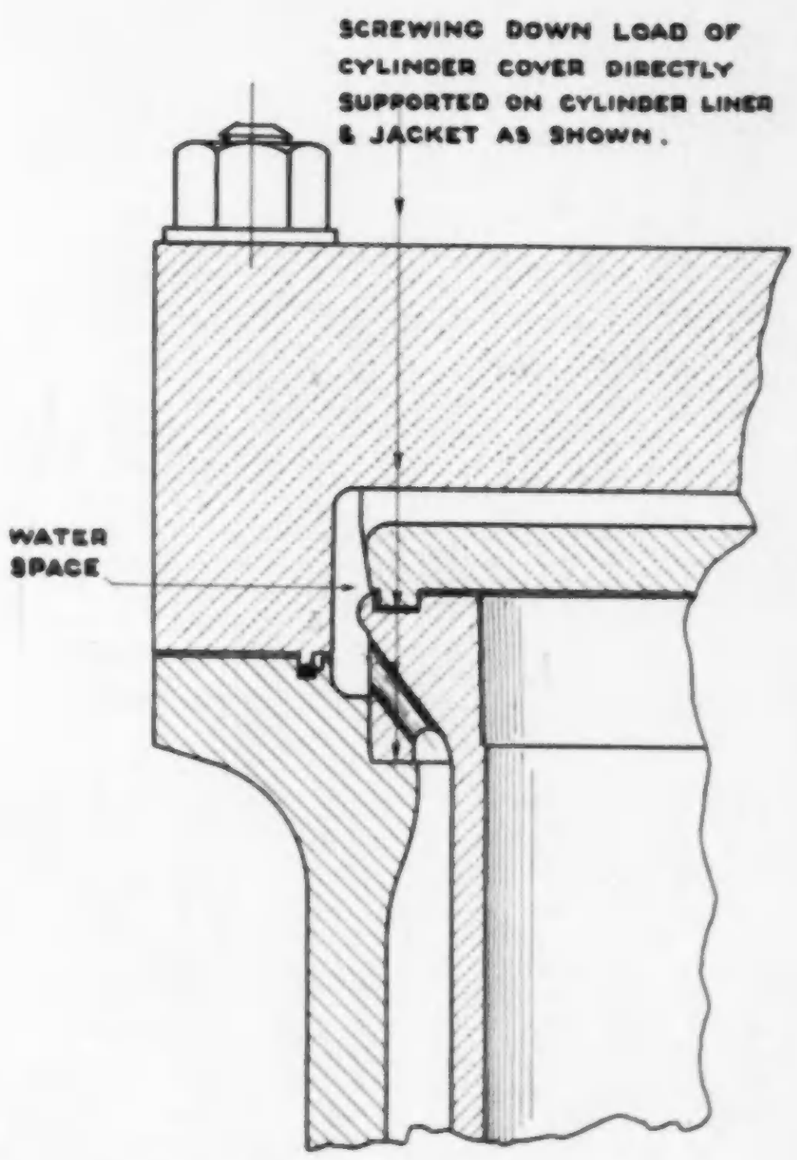


Fig. 2.—Cast-steel liner construction.

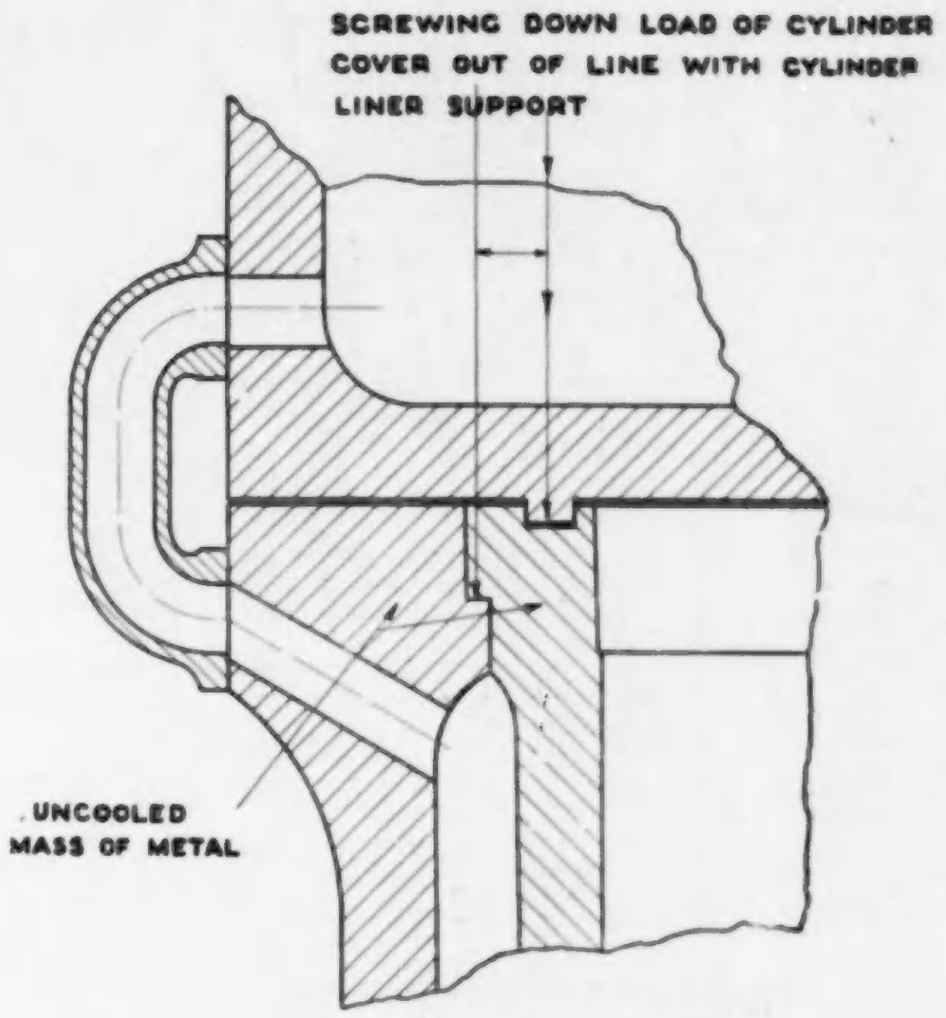


Fig. 3.—Cast-iron liner construction.

of 5/1000 inch wear at the top locality of the piston rings; otherwise the liners are correct in diameter throughout the bore.

In an early three-cylinder engine in which the liners showed signs of abnormal wear at the top after 6,000 hours' running, it was found that the top piston rings had broken, the broken pieces largely contributing to the wear. Further investigation showed that the crankshaft thrusts had worn, resulting in a tilting action being imparted to the piston. This indicated the necessity of providing larger thrust surfaces and improving the forced lubrication feed to the thrust. The broken rings were carefully examined and found to possess insufficient butt clearance, the surfaces of the butts being highly polished. This experience was valuable and emphasized the necessity for providing correct radius on the piston ring corners, and giving the requisite clearance on the butt for expansion.

The three worn liners from this engine were removed and, as reboring the liners would have necessitated the use of oversize pistons, it was decided to repair the liners and restore them to their original dimensions. This was accomplished in the following manner:—

The bore was thoroughly cleaned and the top end of the liners electrically welded for a length of about 9 ins. The process was carried out in two applications, each 4½ ins. long. Every portion of the surface was fused and welded until the whole damaged surface was treated. The dirt scale was ground off by a portable grinder after each operation, and any local defect re-welded. The liners were reground throughout as it was found that the welding, in its cooling, contracted the whole of the liner. The amount of contraction on the liner after welding averaged 5/1000-in., but the design was such that the location of the liner by means of the large gland at the bottom and the locating dowel at the top, permitted an easy fit to be made without the possibility of subsequent movement. This method of repairing a worn steel liner is more complex in description than in actual practice, but if a liner of these proportions can be

repaired at a cost of £15 to £20, the repair is justifiable.

The effect on the liner of the welding process is to increase the hardness of the surface, due to the chilling effect produced by the rapid cooling of the weld. The welded liner, before and after reboring, is shown in fig. 4, while the method of welding is illustrated in fig. 5.

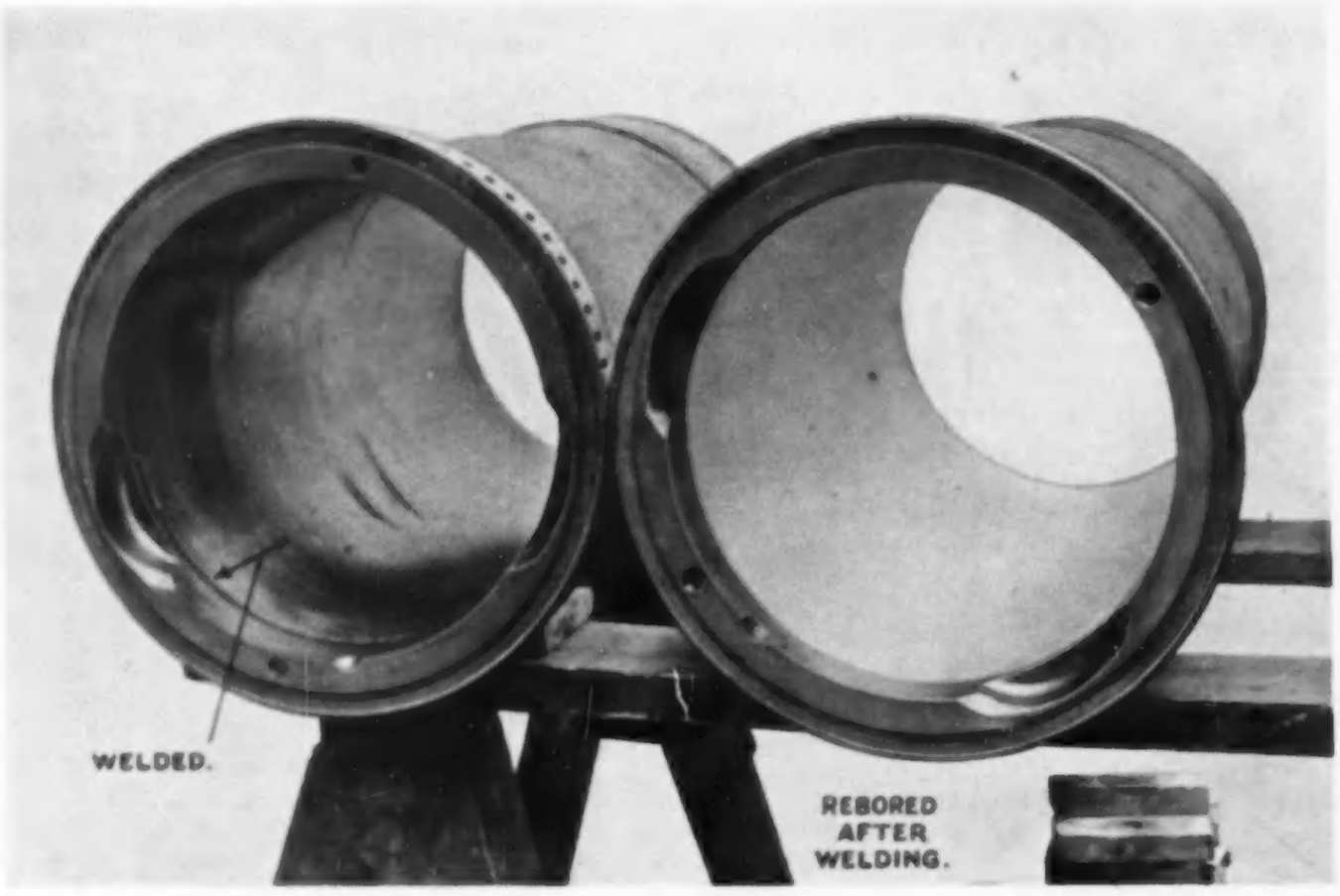


Fig. 4.—Welded cylinder liners before and after re-boring.

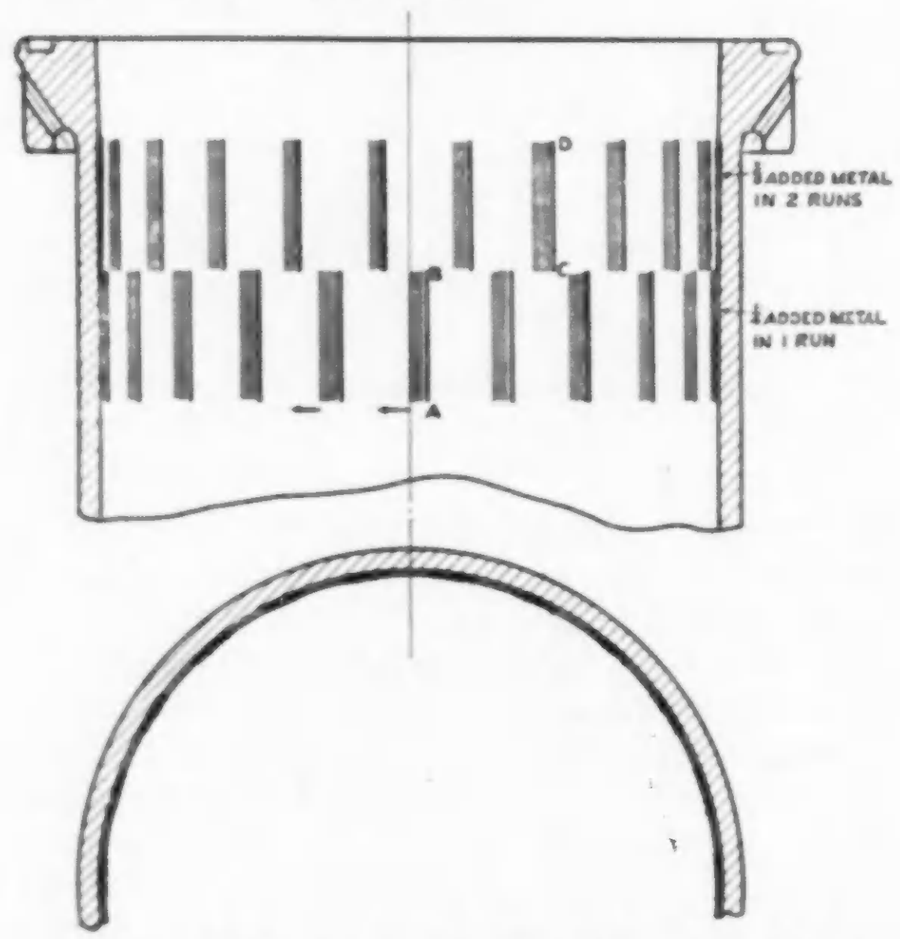
Fig. 5.—Method of welding worn liner.

1st Process :— Start weld at A up to B for a distance of ½" on 24 equidistant spaces.

2nd Process :— Similarly treat C up to D in between AB.

3rd Process :— Grind scale off.

4th Process :— Add another ½ length to AB in direction of arrow and follow at CD.



CYLINDER COVERS.

The reasons for using steel for the liners are equally applicable to the cylinder covers. It was felt that if cast-iron were chosen for this important member, difficulties would be met as a result of having so large a surface exposed to a considerable temperature gradient. It would have been almost impossible to eliminate dangerous heat stresses and consequent cracking of the lower combustion surface.

The construction of the steel cylinder cover has proved most successful. A moderately thin uniform cast-steel combustion plate is fitted on the underside of the cover and is held by through-studs which also secure the valves. The cover is actually made of forged steel, and between this and the plate, cooling water flows at high velocity and passes into the annular passages around the valve cages.

It will thus be seen that the cast-steel combustion plate deals with high temperatures without intro-

ducing any heat disturbance to the cylinder cover proper, and its design permits of a uniform abstraction of heat and a consequent expansion of the plate itself without any detrimental effect to the parts above it.

The air and exhaust valve passages are streamlined in order to deal efficiently with the higher velocities which are now customary; also, the fuel valve can be housed directly in the centre, thus aiding efficient combustion. Furthermore, the cooling water flowing across the combustion plate and thence into and around the valve casings near the valve seats, has a beneficial effect on the latter.

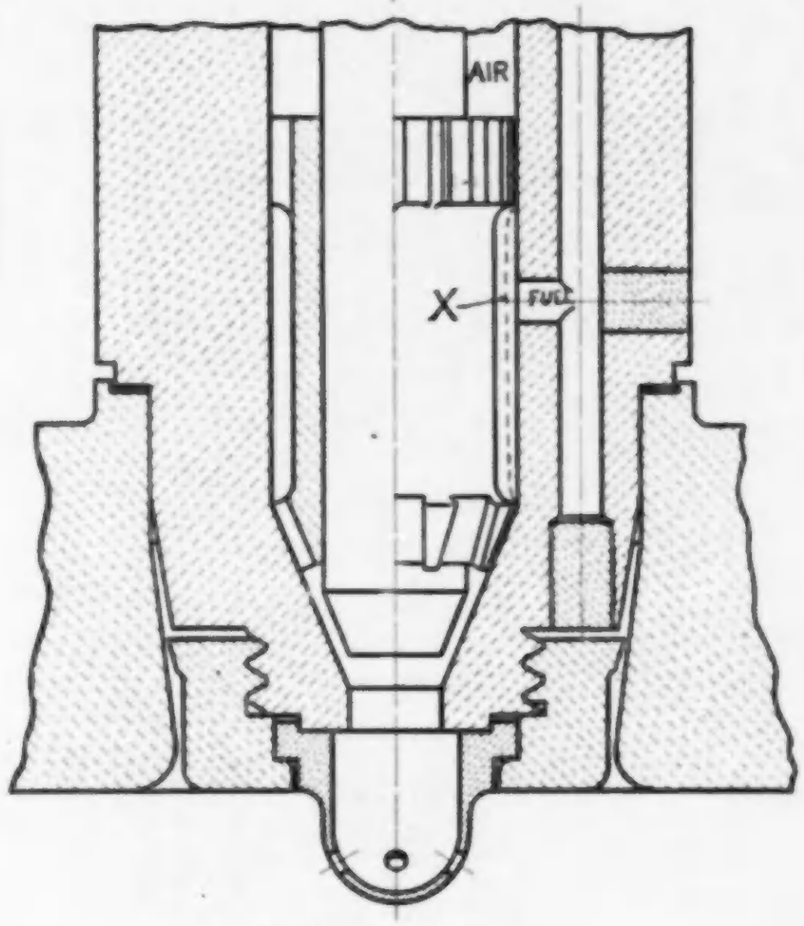


Fig. 6.—Original fuel valve and combustion diagram.

FUEL VALVES AND COMBUSTION.

In the original fuel valve (fig. 6), the so-called pulverizer sleeve was found to be of little value in the manner implied by its name; it really became an air distributor or choke.

By adjustment and reduction of the clearance at "X," the fuel in entering was spread out sideways, which compelled the air to push the fuel in front to the nozzle, thereby preventing a dip in the combustion curve diagram, as shown in fig. 6.

The standard type of air choke and fuel nozzle now fitted are illustrated in figs. 7 and 8. On the compression stroke the fuel is pumped into the conical recess above the seat of the fuel valve. When the fuel valve lifts, the nozzle is blown open, but the cushioning effect of the air under the collars lightens the impact between the nozzle and the retaining nut. The holes in the nozzle are uncovered as they pass the edge of the retaining nut, and the distributing holes, being tangentially drilled, cause a

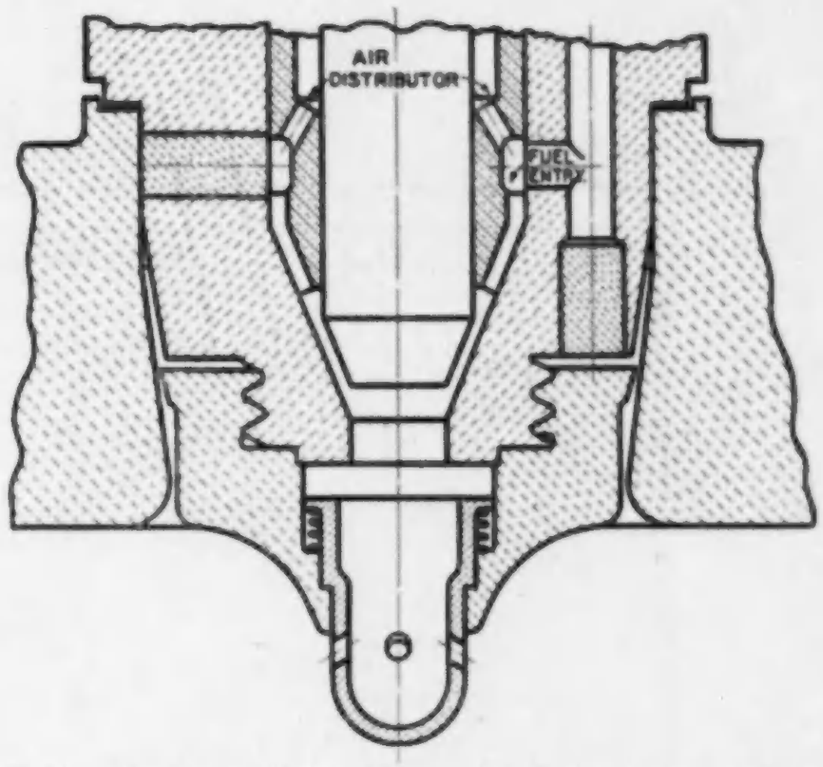


Fig. 7.—Standard fuel valve and nozzle, open position.

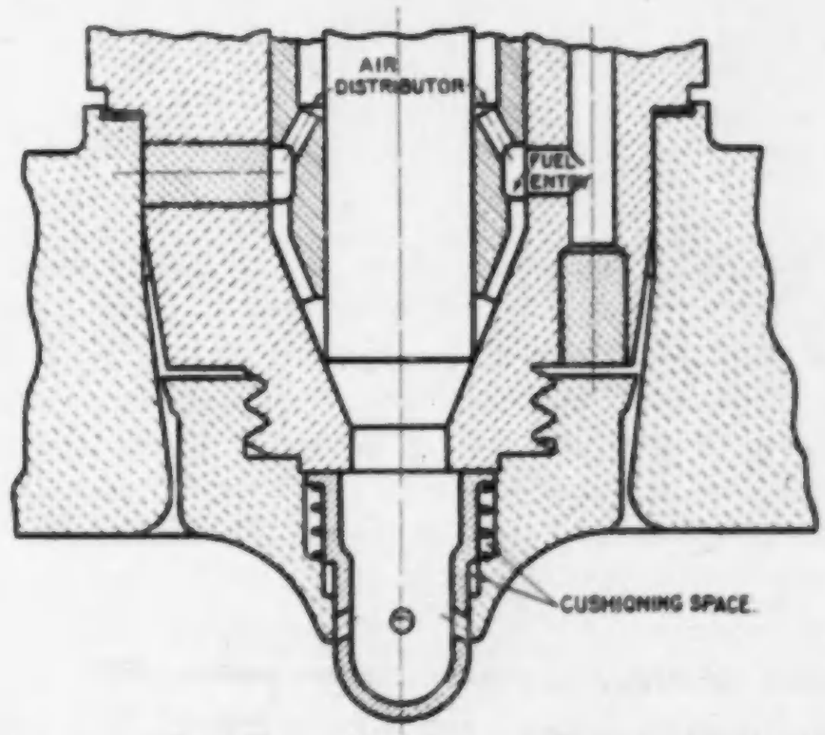


Fig. 8.—Standard fuel valve and nozzle, closed position.

rotary movement to be imparted to the nozzle, giving the following effects:—

1. Gradual entry of spray.
2. A moving and not a fixed spray.
3. Better distribution and turbulence.
4. Prevention of carbon formation on nozzle holes.

When the fuel needle closes, the nozzle returns under the influence of pressure in the cylinder assisted by a spring. As the outside edges of the holes pass the cut-off edge of the returning nut, they receive a surface rub which removes any carbon deposit. With a piston speed of 1,100 ft. per minute, assuming that the injection is completed at 30° after top centre, the fuel must be digested thoroughly in

about $\frac{1}{25}$th of a second before the exhaust valve opens.

As indicated in fig. 9, the angle of spray is approximately 120° and, according to theory, the centre line of each spray should pass through the

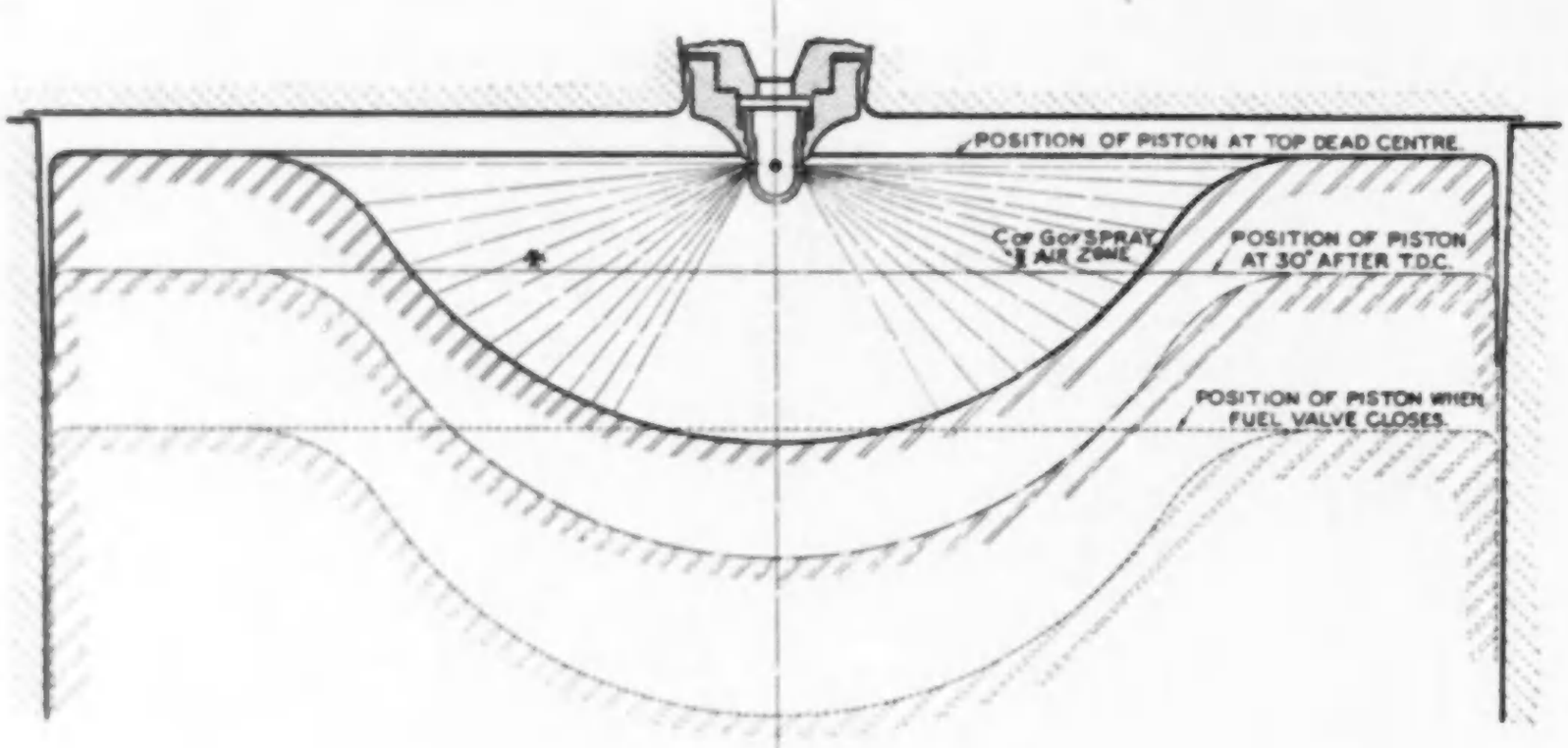

POSITION OF PISTON AT TOP DEAD CENTRE
C OF GOVT SPRAY & AIR ZONE
POSITION OF PISTON AT 30° AFTER T.D.C.
POSITION OF PISTON WHEN FUEL VALVE CLOSES

Fig. 9.—Top of piston and sprays.

centre of gravity of a zone of air, the direction of each spray being such as to prevent contact with its neighbour. With a moving spray, however, it is difficult to determine what actually occurs. There is good reason to assume that the moving spray co-agitates with the turbulent compressed air, resulting in better feeding of the fuel particles and improved consumption.

FUEL PUMPS.

Originally, separate unit pumps were fitted for each cylinder but this design was dropped in favour of one pump body per engine, the body being made of forged steel and accommodating hardened steel plungers, suction valves and separate bronze caps to carry the delivery valves, the plungers working in a close-grained cast-iron guide.

The ratio, $\frac{\text{Vol. of fuel required}}{\text{Vol. of fuel pumped}}$ on an estimated overload consumption of .45 lbs. per b.h.p./hour, is about 1.9. This low ratio is chosen to give closer governing due to the suction valve being closed during a longer period of the delivery stroke. The curves shown in fig. 10 indicate the characteristics of the pump at various loads and the amount of fuel delivered per stroke of each plunger when under governor control.

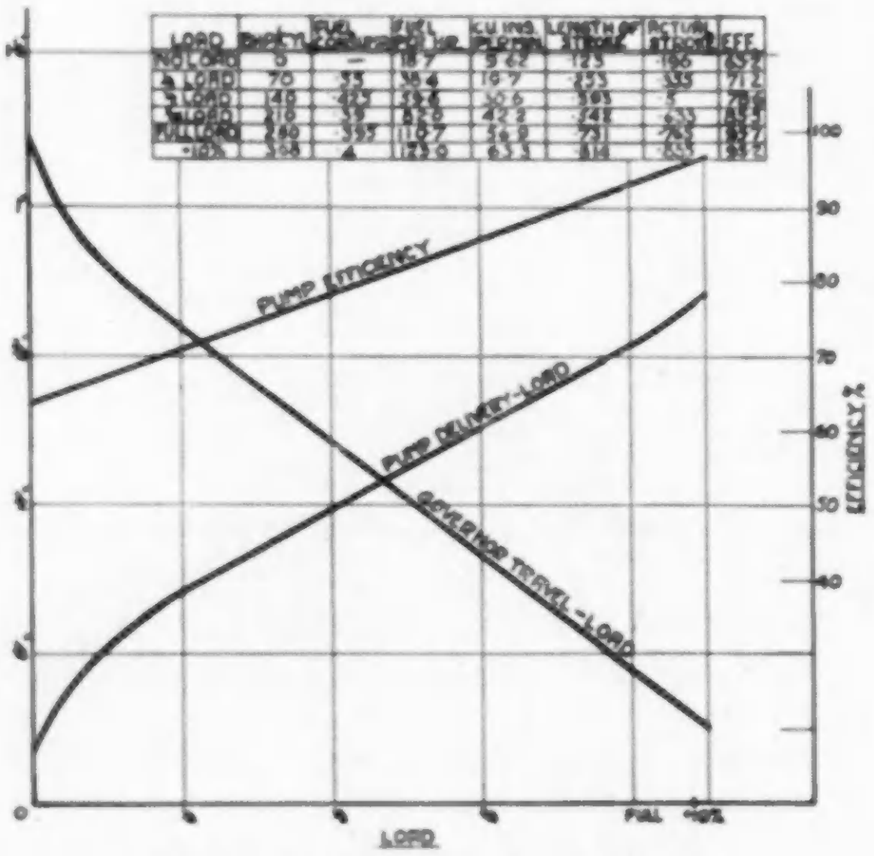


Fig. 10.—Fuel pump characteristics.

Some of the advantages of the latest type of fuel pump are enumerated below :—

(*a*) Any air can escape from the fuel past the guides of the suction valve itself, the pump thus becoming self-venting.

(*b*) Oil fuel can be kept at a constant level without exterior leakage from the pump.

(*c*) Facilities are provided for quick adjustment and regulation.

(*d*) No priming gear is required.

(*e*) Any suction valve can be tripped instantaneously.

(*f*) Any valve can be removed without emptying the pump of fuel.

(*g*) No packings or glands are necessary.

Operating in conjunction with the fuel pump are the overspeed trip gear and the lubricating alarm whistle. The former is a small governor mounted on the vertical shaft and functions at a speed of 320 r.p.m., cutting off the fuel supply to the engine. The lubricating alarm is a simple device which calls attention to lack of lubricating oil pressure, which if persistent, causes a spring-loaded oil dash pot to bring the engine to rest.

FLYWHEELS.

Flywheels are made of cast-steel. It will be appreciated that by reason of the higher peripheral speed allowable, a steel wheel can be made lighter than a cast-iron wheel for storing the same kinetic energy at the same speed, since the cast-iron wheel would have to be smaller in diameter. It would therefore be wider and considerably heavier.

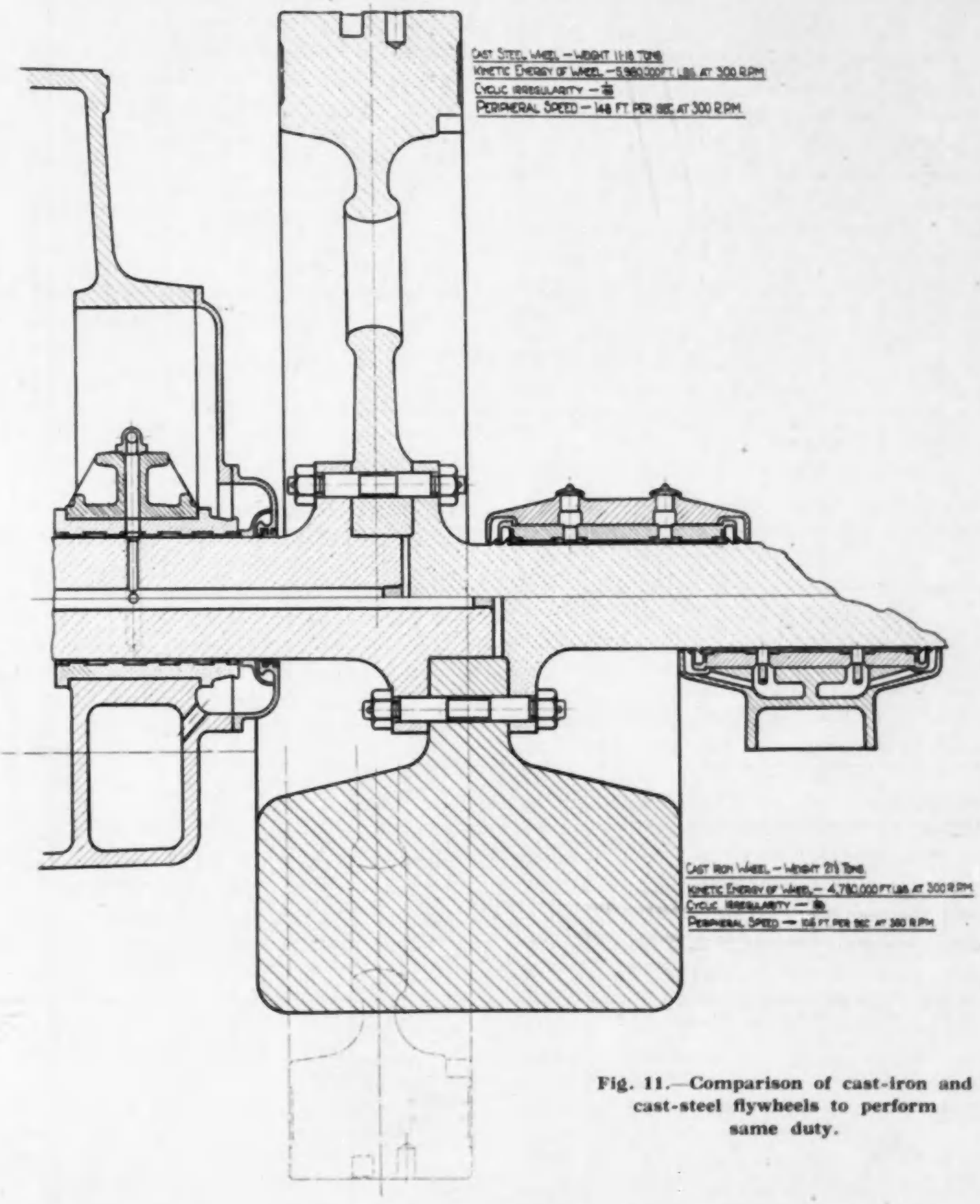

CAST STEEL WHEEL – WEIGHT 11·8 TONS
KINETIC ENERGY OF WHEEL – 5,980,000 FT. LBS AT 300 R.P.M.
CYCLIC IRREGULARITY – 1/48
PERIPHERAL SPEED – 148 FT PER SEC AT 300 R.P.M.
CAST IRON WHEEL – WEIGHT 21½ TONS
KINETIC ENERGY OF WHEEL – 4,780,000 FT LBS AT 300 R.P.M.
CYCLIC IRREGULARITY – 1/48
PERIPHERAL SPEED – 126 FT PER SEC AT 300 R.P.M.

Fig. 11.—Comparison of cast-iron and cast-steel flywheels to perform same duty.

It may be of interest to mention that, for the same cyclic irregularity, a cast-iron wheel would be 3½ times the weight of a cast-steel wheel. The cost of an 8-ton wheel in cast-steel would be approxi-

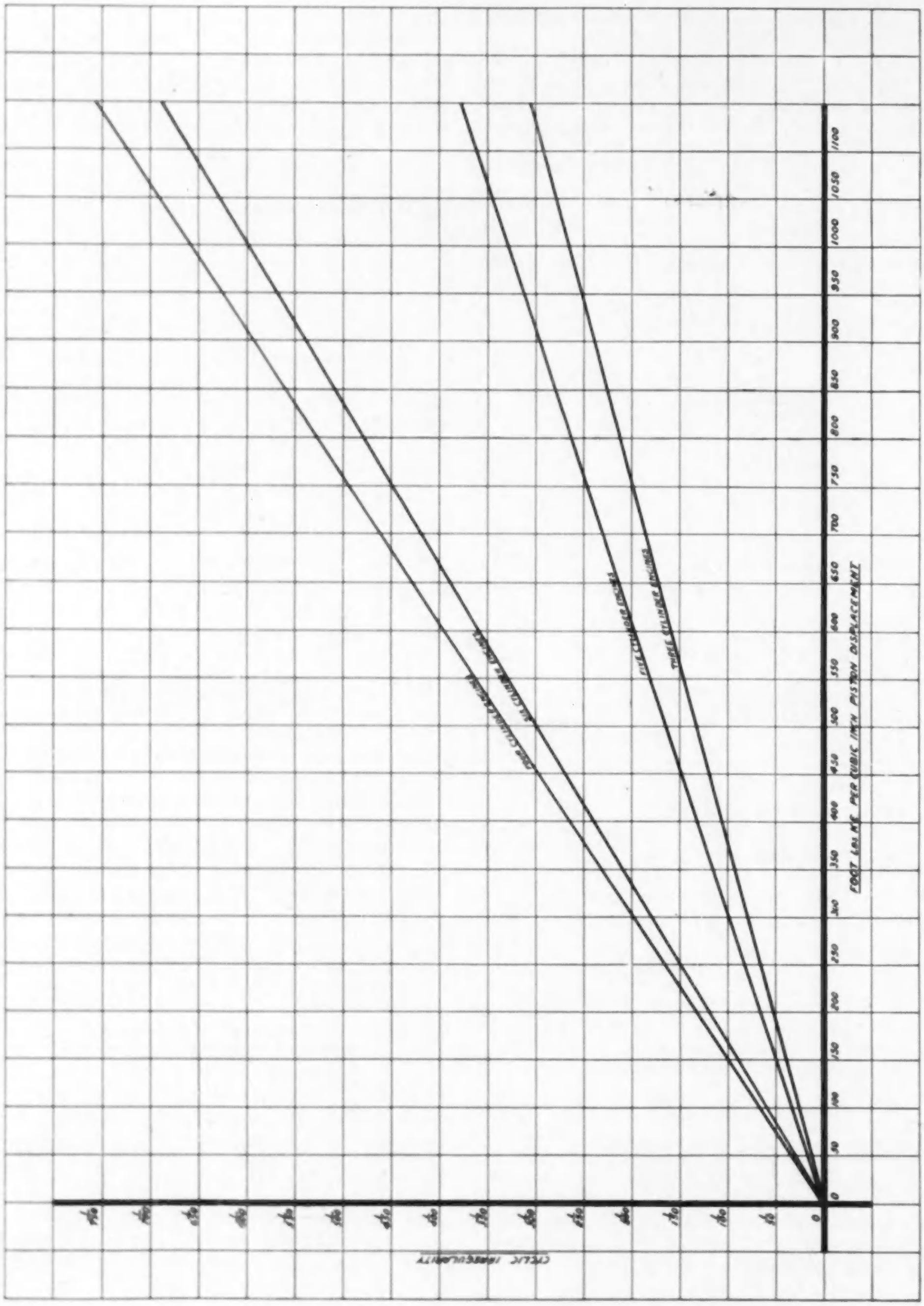


Fig. 12.—Illustrating the K.E. required per cubic inch of piston displacement for multi-cylinder oil engines.

mately £250; on the other hand, a cast-iron wheel of approximately 26 tons weight would be necessary, costing approximately £500. On 5 and 6 crank engines it is sometimes necessary to arrange the flywheel masses as close to the crankshaft as possible, to assist in solving the problem of torsional vibration; with a light flywheel the armature and flywheel weights may be carried without the use of an intermediate bearing. For high power engines a steel wheel is therefore better.

With a smaller number of cranks, heavier wheels are required, but the problem of torsional vibration is not so acute, since the overall length is less. In such cases it is sometimes necessary to interpose a bearing to deal with the additional weight.

Steel castings for flywheels are the only solution for large engines of the calibre under review. A high factor of safety is maintained, although the peripheral speed is 50 per cent. higher than that of cast-iron wheels.

In fig. 11 are illustrated the outlines of a cast-steel and cast-iron wheel to perform the same duty; it will be observed that the cast-iron design is impracticable. All flywheels are of the disc web type, and are sandwiched between the driving and the driven couplings. Fitted double-ended bolts secure and drive the electrical generator without the use of keys. The periphery of each flywheel is clearly graduated into 360 degree divisions and all lifting holes in the disc are given a bulbed section around the edges for strength.

The curves (fig. 12) show the kinetic energy required per cubic inch of piston displacement for 3, 4, 5 and 6-cylinder engines. Generally, a cyclic irregularity of 1/180 is chosen for D.C. and 1/250 for A.C. machines. It will be observed that the 3 and 5-cylinder engines require heavier flywheels than the 4 and 6-cylinder engines. The values of kinetic energy for the above co-efficients are taken from actual flywheels whose sizes and weights are deduced from the usual T.M. diagrams, in conjunction with torsional oscillation findings.

PISTONS.

Much controversy has centred around the use of aluminium alloy for pistons, especially where these are of large diameter. The chief objections raised against the use of this metal for pistons have been:

1. High cost of production.
2. More rapid wear of cylinder liners.
3. Higher lubricating oil consumption.
4. Distortion and its accompanying evils.

The question naturally follows: why, in face of these so-called disadvantages, are aluminium pistons still used? Briefly the reasons are these:—

1. Reciprocating weight must be as small as possible, not only on account of primary and secondary balancing, but also because friction due to inertia must be reduced to a minimum to obtain a high mechanical efficiency.
2. The metal must possess a high heat conductivity.
3. For a relatively high m.i.p. a piston is required that will give long and durable service without cracking, and in the event of seizure, the resultant damage must be slight.

Experiences with the early aluminium alloy pistons vary; in some cases they have not been altogether satisfactory, especially when used with cast iron liners. There are instances in which alloy pistons have scored the liners and others where the crowns have cracked. The former trouble may have been due to the presence of grit on the liner which eventually became embedded in the relatively soft aluminium, subsequently acting as an abrasive. Scoring may also have been due to the action of small pieces of hard aluminium oxide produced by the oxidation of fine particles of aluminium rubbed off the piston.

Cracking of the heads may have been due either to faulty design or to the position of the lifting holes; proper support of the combustion crown may have been lacking and insufficient metal available to conduct away the heat to the piston walls. Probably the real cause of most of the trouble was the use of an inferior alloy which had been given improper heat treatment. Pistons do not seize due to overloading of the bearing surface; 70 per cent. of the seizures are due to insufficient allowance being made for expansion or distortion; the remaining 30 per cent. can be traced to complete failure of either the water or oil supply or to the condition of the lubricant adhering to the cylinder walls.

The metal used in the pistons under review is a "Y" alloy. It receives drastic heat treatment until a Brinell hardness number as high as 120 is reached. During the years that these aluminium pistons have been employed not one has cracked sufficiently to warrant scrapping.

In the standard piston now used the skirt and gudgeon housing are in one piece, square recesses being provided for the bronze bushes. Aluminium bushes are, at the moment, being tried and are made in halves, steel caps with through-bolts securing them to the piston. All protrusions of metal within the piston for carrying the bearings are kept symmetrical and of even thickness. The piston head is bedded to the cover of the skirt by means of a circumferential tongue which prevents leakage of oil if any movement of distortion takes place. This piston is a decided improvement on the original and

continues to operate satisfactorily. Indeed, it is quite common for full load to be applied to engines fitted with these pistons within three minutes of starting, so that the pistons behave in this respect as well as those of cast-iron and of orthodox design.

An occasion in which a heavy seizure of a piston in a six-cylinder engine occurred gave a most illuminating insight into the behaviour and strength of the various parts subjected to such a severe shock. It was found that five minutes after the seizure the engine could be barred round, demonstrating that any slight fusion between the piston and the steel liner had quickly broken down after contraction had set in.

The liner was honed and cleared of the aluminium adhesion, and calibration showed no distortion in the liner. Within twelve hours a new piston and rod were in place and the engine in commission again. The piston had seized on practically the whole of its surface, particularly at the four points where the section of the metal is irregular around the gudgeon pin.

Had the piston and liner been made of cast iron it is almost certain that the seizure would have been of sufficient intensity to have been disastrous.

Experience has therefore shown that, apart from the many advantages obtained by the use of aluminium for pistons, there always exists, as in most trunk pistons, the disadvantage arising from distortion due to irregularity of the metal in and around the gudgeon pin housing. The "four" scores on any seized piston and liner indicate this very clearly.

Piston slap is not any more audible than with cast iron pistons, for by virtue of correct cooling of the piston head and the efficient and rapid heat transfer through the thin cylinder liner, the expansion in the lower part of the piston skirt warrants only 1½-inch thousandths clearance per inch of diameter, which is practically the same as that given to large cast-iron pistons.

Some of the disadvantages of existing pistons may be summarized as follows :—

1. An internal weakness to be found in all pistons, whether cast iron, cast steel or aluminium, is that the combustion load has to be taken from the sides of the piston to the connecting rod, tending to deflect both pin and piston.

2.—Care and precision are necessary to make and keep the pistons longitudinally square.

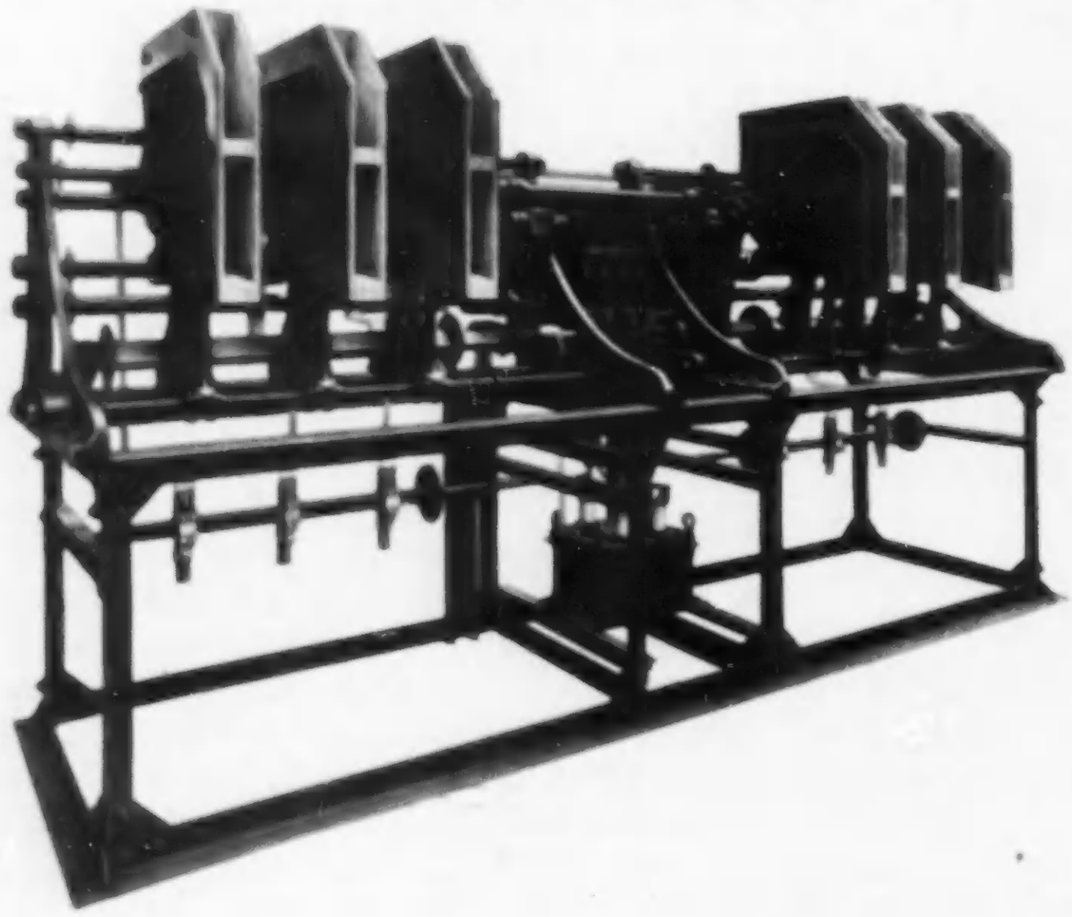
3.—All trunk pistons are a fixture to the connecting rod in one plane through the medium of the gudgeon pin, no matter whether the pin floats or is fixed at its ends or is fixed in the connecting rod.

4.—Any springing in the crankshaft, either by wear in the bearings or deflection due to load, transmits heavy reactions to the pistons, sometimes tilting them.

5.—In most trunk pistons bearing adjustment is impossible without removing the piston from the cylinder and in larger engines this entails hours of work.

[*To be concluded.*]

Reversing Contactor for Rand Mines.



The 2,200-volt, 400-amp reversing contactor illustrated is part of a large winder equipment in course of manufacture for No. 16 shaft of the Rand Mines. As the supply system is liable to large voltage surges, the insulation is designed to withstand a pressure test of 30,000 volts.

The construction is of metal and micanite and each set of contacts is operated by a 3-phase magnet, the "forward" and "reverse" sets being interlocked mechanically and electrically. Special means of securing an effective arc rupture are included.